BIOLOGY

for Christian Schools®

SECOND EDITION

TEACHER'S EDITION BOOK 1

BIOLOGY

for Christian Schools®
Teacher's Edition

Second Edition

Book 1

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BIOLOGY for Christian Schools® Teacher's Edition
Second Edition

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A Survey Course in Biology

In courses like mathematics, foreign language, or grammar, a teacher must teach for *mastery* of each concept and procedure, for the student's ability to understand or use a new concept may depend upon mastery of a former concept. In courses like history, or biology, however, the student often does not need to master all of the concepts and details in one unit to understand the next unit. A mastery of plant classification and anatomy may have little to do with a student's grasp of zoology or human anatomy and physiology. Of course, a thorough understanding of the preceding unit is helpful and may be necessary for understanding some concepts in following units, but complete mastery is not essential. For example, a knowledge of plant classification and anatomy may be helpful in an ecology unit. But a high school level of proficiency in ecology does not demand mastery of all plant classifications or anatomical structures; just an understanding of the basics is needed.

Some scientific facts and concepts are essential to further understanding in science, especially in math-oriented areas such as physics and chemistry. Even in areas that are not necessarily math oriented, a certain level of mastery is important. For example, a basic understanding of cellular structure and function is essential to a good understanding of human physiology. However, complete mastery of the origin, insertion, and function of fifty muscles is not essential. A good teacher will probably point out these facts about a few muscles, especially in teaching principles of muscular function and body design. A good teacher may ask the students to learn the origin, insertion, and function of a few muscles, but his test will stress the principles illustrated by the muscles, not merely the list of muscle names, origins, insertions, and functions.

A good high school biology course will not overwhelm students by requiring mastery of such things as gymnosperm life cycles or the structural formula of the glucose molecule. An awareness of these facts may help them understand the subject matter thoroughly, but in high school the emphasis should be on *surveying* the material, not *mastering* it. The details of biology may make tests easier to write, but they are unnecessarily cumbersome to the learner.

The teacher who stresses the mastery of biological details will miss the main point of the Christian high school survey course–**exposing the students to the scope of biology, with special emphasis on subjects and concepts that will affect their decisions about themselves and their spiritual standards.**

The students need to be aware of but do not need to master, for instance, the basic concept of DNA structure and its replication. They need awareness of this concept to understand the genetic material, which is essential not only to understanding life but also to making decisions about many spiritual matters. For example, DNA structure is related to mutations, which form the basis for one of the primary scientific arguments against biological evolutionary theory. In addition, many of the major spiritual/scientific decisions made by the next generation will be in the realm of genetics. Intelligent decisions about eugenic research, genetic engineering, test-tube babies, and artificial insemination require an understanding of DNA. However, to have students memorize the atomic structure of the nucleotides or the sequence of amino acids in a particular protein is mostly wasted effort.

A good high school biology teacher will teach principles and use details to support them. Of course, students should master and be tested over some details. Let the students know which details should be mastered and which are supplementary. The guidelines the teacher establishes, the experience of a few weeks in class, and a test or two usually teach students to distinguish the material that they should master from what is less important for them to know. Then the teacher needs to remain consistent.

Although *BIOLOGY for Christian Schools®* has been designed with the philosophy stated above, teachers with other philosophies can use the text. Their use, however, will differ considerably from that of those who hold the survey-course concept. The following portion of the *BIOLOGY for Christian Schools® Teacher's Edition* contains teaching tips, goals, and guidelines for a survey course in biology.

Teaching Vocabulary

As the *Introduction for the Student* (pp. vii-ix) points out, vocabulary is one of the major thrusts of any study. Biology has been blessed (and cursed) with a large, often confusing, and sometimes petty vocabulary. Teaching the biological terms with the approach "Here is the word; *memorize* its spelling and definition, and be able to use it in a sentence" will take the life out of the class. This knowledge may be the goal, but do not try to get it across that way. Use positive methods to teach the vocabulary of biology.

Etymologies

Many words in *BIOLOGY for Christian Schools®* have been marked with an asterisk and have a simplified etymology in the lower margin. (In this Teacher's Edition they appear in the upper left- or right-hand margins.) Discuss with the students the fact that if they learn certain combining forms, they will find many words not only easier to learn but also easier to remember. Tell the students right away that they will be told which etymologies are important for them and that they will be responsible for only those. This will relieve their fears that they will have to learn *all* of them. Making students responsible for all these etymologies will have this result: students who are good at memorizing will do well on tests and quizzes; others will be needlessly frustrated.

On pages T22-T32 of Book 1 of the Teacher's Edition is a chapter-by-chapter listing of the significant combining forms used (also Book 2, pp. T16-T26). Introduce these forms with the words in that chapter. Inform students that if a combining form is pointed out, they are expected to know it for testing purposes, not only on the next test but on all future tests. Consider providing a list of the combining forms for which they are responsible (chapter by chapter), or have the students keep a running list.

The first time a combining form is used in the text, the Teacher's Edition section gives other words used in the text as well as other words that use the root. This section can be helpful when presenting the combining forms to students. Teachers may not wish to present all of the combining forms suggested for some of the early chapters. (The sections are long for some chapters.) Consider saving a few combining forms to present in later chapters in which they reappear.

If, on the day before a test, the teacher is pointing out to the class which combining forms will be on the test, the etymologies have not been used wisely. Treated this way, the etymologies become the old "list of spelling words." Instead, introduce each term when presenting the material, and then ask students for a breakdown of the word. (This not only encourages them to read the etymologies as they read the assignment but also reinforces the earlier statements about the value of learning combining forms.) Students soon become adept at this, and, before long, learning etymologies becomes simple.

Biological Terms

The section of Biological Terms at the end of each chapter (note explanation in *Introduction for the Student,* p. viii) should show the student whether he has learned the material and what he needs to study. A good teacher will define each of these terms several times and use them frequently while covering the material. By the time they have a test, most students should be familiar with the terms. If not, they have reason for concern–and that concern should result in their seeking out the definition and learning it. Stress this function of the Biological Terms section to the students at the beginning of the course and after the first few tests. This guideline will help most students study if they use it properly.

To teach a term, simply *use* it. Thoroughly explain its definition, cover its etymology (if possible), and then use it frequently. (Any term, emphasized or not, that is not used thoroughly in class discussion is too obscure to expect students to learn.) Using the term will enable the students to learn it without the memorization process.

The section of Biological Terms at the end of each chapter can become a burden to the student if the teacher is not careful. One way to frustrate the students with the terms is to have them write out a definition for each term after they have read that section of the chapter. For intelligent students, this is mere busywork–the sort of thing that makes school boring. For the student who lacks motivation, this will be the millstone about his neck that will alienate him completely from biology. For the student who has difficulty with school, such a technique is all too often unsuccessful. Occasionally, however, a student who is having trouble grasping the material will profit from writing definitions for the terms. Judge these situations carefully (see *Using Review and Thought Questions,* Book 1, p. T8).

There is another way to misuse the terms. The teacher who stands before the class, writes a word, dictates a definition, then writes the next word and dictates its definition, *ad infinitum,* deserves to be wrapped in the notebook paper the students waste (for in such cases there is little communication from written material to the student's mind) and left in the tomb he calls his classroom. He will neither suffer nor decompose; his mind is pickled, and no living bacteria or fungi will attack materials kept in cold classrooms. There is a place for the written term and the dictated definition, but they should be used rarely.

Visual Aids

Many educators stress the use of visual aids almost to the extent that, rather than using the visuals, the teacher merely assists them. It is tempting to use the abundant prepared visuals (classroom aids such as charts, transparencies, and films) and the abundant biological natural visuals (specimens, demonstrations, and objects in the classroom) as a crutch to support poor teaching. The *hands-on* movement, as well-meaning as it may be, fosters the use of visuals so that a teacher thinks he is doing a good job as long as his students are fingering, cutting, or staring at something. Real learning may or may not be going on. Too many hours spent in dissecting, leaf collecting, observing a shell collection, or using many of the "prepared" visuals often amounts to wasted time.

Visual aids *can* be very valuable in the classroom. It is possible to use many good visuals legitimately in a single class hour, but do not use them merely for their own sake. Except for times when they gain or hold attention, if visual aids do not support a principle or help the student *visualize* some significant point related to a principle, they are being used improperly.

Films and Video Tapes

Because visuals should support principles, most of the available educational science films, video tapes, and filmstrips cannot be recommended. Some of them present good scientific concepts, and some of them use good educational methodology (those that do are frequently old and draw more attention to their age than to the material they are trying to teach). All too often, educational films and video tapes contain principles that contradict the principles upon which a Christian high school biology course should be built. Too often poor philosophy is allowed into the classroom under the guise of "good education" in a film. Carefully preview any film or video tape used in the Christian classroom; if it has weaknesses in its principles or presents an anti-Christian philosophy, carefully counteract these points. If it takes more time to attack the philosophy and principles of the film than it does to teach the concepts it presents, do not waste class time by showing the film.

A good number of video tapes on various nature topics are available. Many of these have excellent sections which can be used in high school biology classes. Since these desirable sections are often surrounded by objectionable materials, it is wise for the teacher to show only those sections which are profitable. Often the sections a teacher wants to use in a teaching situation are embedded in a video that does not go along with the topic under discussion. For example, an eight-minute section on the sea lamprey may be in an hour-long video on the ecology of the Great Lakes. Showing the whole video when teaching about the lamprey would present much information about the Great Lakes which is not relevant to the topic at hand. Some of the other sections may be useful in other units, but at this time they would be extra and might even confuse some students regarding what is and is not important to know for testing purposes. Showing the entire video, unless there is extra time, would not be wise.

The ease with which video tapes can be shown in the classroom and the comparative simplicity with which video tape players can be set for certain sections make them useful in most Christian biology classrooms. (Bob Jones University Press stocks a number of Christian video tapes which are useful in teaching biology. Contact Customer Services, 1-800-845-5731, and request information about video tapes.)

Video disks for teaching biology are becoming available. Although expensive, many of them are exceptionally good. They can be programmed to show any of thousands of images or even short video sections in any sequence. These visual devices will be a major part of the educational trend of the future. Since the teacher is in control, they have great potential for use in the Christian biology classroom.

Other Prepared Visual Aids

With the exception of the few acceptable films, video tapes, and filmstrips, the most effective prepared visual aids are those that the teacher controls. Film loops, slides, wall charts, overhead projector transparencies, and posters can all be used successfully. A packet of overhead projector visuals designed to go with this textbook is available. *BIOLOGY for Christian Schools® Visuals Packet* includes outlines, diagrams, charts, and tables–some taken from the text, others supplementary or complementary to it. The market is full of various biological visuals which can also be used (see Table TE-3 in Book 1, p. T22, and Book 2, p. T16).

Take great care to spend visual aid funds wisely to meet the particular needs of the class. If you live on the coast, for example, and students are familiar with starfish, purchasing a costly film loop on starfish habitat and movement would not be as wise as purchasing a film loop on animals of the grasslands. Charts and tables for an overhead projector are much less expensive than a

good wall chart of the same material. If, however, the chart will be used in the classroom for a long time, or if it needs to be a visible reference for several class hours, a wall chart may be the best buy.

Some of the best prepared visual aids for biology classes are 35 mm slides. Good collections as well as individual slides are readily available and relatively inexpensive. Do not overlook sources such as zoos, parks, and other exhibits you visit while traveling. Consider adding personal slides to the teaching collection. Arrange slides to reinforce the content and principles that you wish to communicate.

Some of the best visuals in any classroom are the ones that you, the teacher, have prepared yourself. Bulletin boards, overhead projector transparencies, charts, tables, and posters that you develop and carefully use are generally the ones that best teach the content principles of the course.

The Textbook as a Visual Aid

One often overlooked visual aid is the textbook. The charts and tables in *BIOLOGY for Christian Schools* have been prepared not only for student reference but also for teacher-classroom use. While using textbook visuals, reinforce for the students which material is supplemental and which they need to know. Not every chart and picture in the book can or should be used this way. The Teacher's Edition contains notes on using the illustrations and charts intended for class discussion. Often a helpful illustration or chart found in another area of the book is noted. Some of the transparencies in the visual packet are copies of the illustrations in the text and are thus useful when presenting the text material.

The textbook visuals can also help students sort out material. For example, it is often difficult for students to know which men of science are important enough to memorize and which are merely mentioned in passing. Some teachers find it practical to tell the students that if the man's picture appears in the chapter, they should know his name, accomplishments, nationality, and the time frame (maybe not the exact dates) in which he lived. This policy is a starting point which can be amended for individual chapters. Establishing similar policies for material such as structural formulas and lists of diseases and disorders is also a good idea.

Laboratory Activities

Most states require that 20% of biology class time be devoted to laboratory activities. This time includes not only students' "hands-on" laboratory work but also field work and demonstrations by the teacher. Devoting 20% of the class time to such activities is a good guideline. With the exception of a few suggested demonstrations and some field work suggestions, this text does not include laboratory exercises. *Laboratory Manual: BIOLOGY for Christian Schools®* is recommended for use with this text. See the Teacher's Edition of that text for more information about laboratory activities.

Overview of Teaching *BIOLOGY for Christian Schools®*

BIOLOGY for Christian Schools is designed for a high school survey course touching on most of the major areas of the biological sciences. Written for the reading level and interest of tenth grade students, it stresses concepts that are significant to all Christians. It emphasizes areas of biology that overlap Christian philosophy, morals, and ethics. Some areas of biological study are therefore dealt with here in greater depth than in many other high school biology texts, while other areas have been greatly reduced or eliminated.

Most school years are about 36 weeks long. If 18 pages of reading per week are assigned, the entire content of *BIOLOGY for Christian Schools* can be covered in a school year. These 18 pages will not adjust to 4 assignments of 4 $\frac{1}{2}$ pages each. Some nights, the students may read 8 or 10 pages (depending on the content and number of pictures), and other nights they may read nothing while they study for a test or prepare for a laboratory exercise or science fair project. Of course, some weeks it will not be possible to cover 18 pages; other times it will be simple to teach more than 18 pages in a week's time. The difference lies in the content, the scientific background of the students, and the depth of coverage.

The notes for each chapter indicate how many class periods can or should be spent in teaching each section. Teachers will vary these suggested times based on how thoroughly they wish to cover certain topics, how much they want to omit, the intelligence and background of their students, and various other factors. Table TE-1 (Book 1, pp. T10-T19; Book 2, pp. T4-T13) is a guideline for covering the text in thirty-four to thirty-five weeks. Since activities, vacations, and schedules vary from school to school, these assignment schedule suggestions will require modification.

Planning a Survey Course in Biology

Most of the material in *BIOLOGY for Christian Schools* is basic for a comprehensive understanding of biology and would be useful for a person making Scriptural and biological-related decisions. This does not mean that every teacher must, or even should, teach every word of material in this text. There are materials which will be considered supplemental, nonessential, or boring by some teachers. Another teacher will consider the same material essential and exciting. Some teachers will teach some material to one class but omit it in another class because of the ability of the class, the geographic location, the time of year, or any of a dozen other reasons. What is taught in a class and what is omitted must be the choice of a competent teacher. A textbook, in part, can be judged by its ability to be used by a wide variety of teachers in a wide variety of situations.

A good teacher will outline his course before he begins teaching. Many teachers will find the outline of this text to be ideal, but for some, the outline will need to be adjusted. Following his decisions regarding sequence, the teacher should allot time to various sections of the outline. Many teachers will find the *Time Frame* found at the opening of each chapter useful in deciding how much time to spend on each section.

Teachers will want to adjust the length of time they spend on various sections based on several criteria. Some of the obvious criteria include the following:

- ❑ The significance of the material and the relevance of it to the students' future lives in our society.
- ❑ The need of understanding the material in order to make spiritual decisions.
- ❑ The need of understanding the material for future study (in this course or in future courses).
- ❑ The need of understanding the material vs. the need of exposure to the material.
- ❑ The difficulty of teaching the material.
- ❑ The academic background of the students.
- ❑ Student interest in the material.
- ❑ The teacher's interest in (and sometimes his understanding of) the material.
- ❑ School policy, class projects, and other activities which may affect the rate at which progress can be made in a class.
- ❑ The availability of materials for teaching.

After their original allotment of time to the various units they would like to teach, most teachers find that they have too much material to cover and will need to make adjustments. Most teachers find that omitting a few pages in one chapter, skimming the end of some other chapter, and covering a section of another chapter in just a few sentences are more in keeping with their educational goals in the biology classroom than teaching every page of the book until they run out of time. In this way, the teacher decides what to teach. Material is omitted by design, not by default.

The notes in this Teacher Edition and in chart TE-1 (Book 1, pp. T10-T19; Book 2, pp. T4-T13) help the teacher decide what to cover in depth, what to skim, and what to omit.

This edition of *BIOLOGY for Christian Schools®* has several features that make it more flexible and more useful than the previous edition. The placement of *Review Questions* at key points in the chapter rather than at its end permits teachers to select sections of chapters that they wish to skim or omit. A considerable amount of material has been placed in boxes which a teacher can cover, skim, or omit. Sometimes a teacher may wish to have students read a box to be exposed to its content but not cover it in class or on tests.

One of the major new features of *BIOLOGY for Christian Schools* which makes the text flexible and which will prove interesting to many students is the *Facets of Biology* sections. Within each chapter there may be several Facets. Facets deal with material related to the primary discussion of the chapter but are set off from the chapter (see *Introduction for the Student*, p. ix). The Teacher's Edition Notes include suggestions for the use of each Facet.

Some Facets cover essential material which must be covered to permit understanding of biological concepts presented later in the book. These Facets, along with the future material in the text which they illuminate, are labeled.

Most of the Facets contain supplemental material. These Facets often have interesting additional examples which modify or add to the content of the chapter. Teachers are encouraged to evaluate the inclusion of these Facets as part of the course. If the teacher is running behind on the time allotted to a section, skimming or omitting a Facet may be a good method of getting back on schedule. Sometimes it may be helpful to have students read these Facets but not cover them in class or on the test.

Many Facets deal with Scriptural or current biological concerns. These Facets should not be completely omitted. The instructor can obtain adequate coverage of them by having the students read them and then by making a few comments about them in class.

Some Facets are designed for enrichment of advanced students. These Facets will also be useful if a teacher is going to go into depth in a particular study or if this book is being used as the basis for an advanced course. Teachers of basic biology courses or teachers who have students who are finding the material difficult are encouraged to omit these Facets.

The Teacher's Edition Notes indicate what kind of material is in each Facet and suggest how to cover the material. No matter how the content of the Facets is covered, students should be told what material is significant and what they should know for testing purposes. As part of the assignment sheet (or however assignments are given), tell students whether they are to read the Facet, what they should do about the *Facet Review Questions*, whether they are responsible for the boldface or italic terms, and whether the content of the Facet will be on the test.

Some schools may be tempted to use Unit III (human anatomy and physiology) as the text for an elective second-year biology course. If this course is not taken by all students, it would be unfortunate. This unit contains material basic to a good understanding of biological issues faced by everyone. A good second-year course in biology should contain in-depth studies of cellular structure and physiology, advanced ecological principles, organic chemistry, and organism physiology to prepare students adequately for further biological studies in college.

The teacher of an advanced high school course in biology can find some of the materials in this text useful, especially if the material coordinates with the material covered in the introductory course. An effective advanced high school course in biology can be taught by adding readings in various periodicals, other texts (including some sections of college texts), and some other sources to the advanced materials found in this text.

Assignments

Our modern Christian society requires much of a student's out-of-class time. Special services, practices, rehearsals, work, and family activities consume major portions of a student's time. Class time, however, can be profitable only if the student is at least somewhat prepared by having read the text. If students review, learn, and on occasion memorize text material at home and not always in class, the teacher can bring in material which augments, explains, supplements, applies, and illustrates the text. Without homework, the high school teacher is not really free to teach.

A teacher finds himself in a dilemma. Homework is profitable, but excessive homework is undesirable. A good part of the answer is flexibility, with individuals as well as with the group. For a survey course, in which mastery of most material is not crucial, the assignment sheet is a good place to be flexible.

The Assignment Sheet

Ideally, an assignment sheet should be given to the students for as long a period as possible–a grading period or a semester at a time. Often, however, such advance planning, especially if the teacher is new to the course, is not possible. Prepare assignment sheets that cover entire units (from test to test) or at least one week at a time. The student can take most activities (even the special activity that has been planned in advance) in stride if he can budget his time and plan for them. If the student finds out on the day of the activity that he has heavy assignments in several courses, either the assignment or the activity will be doomed. (Unfortunately, as far as many students–and their parents–are concerned, the days of doomed *activities* are past.) Some conflicts are unavoidable and require special exceptions.

In a mastery class like math or English grammar, an assignment may depend on past mastery. Exercises and review must sometimes be added, greatly altering the class rate of progress and making an assignment sheet a veritable impossibility for the novice teacher. In a survey class, like biology or English literature, the fact that a student is a day or two ahead on his reading assignments (or equally–but do not tell them this–a day or two behind) matters little. There are fixed points of accountability (such as quiz days, test days, or days when written assignments must be turned in) for the standard reading assignment; so students can easily get ahead and have almost any evening relatively homework-free in a survey class. They can do this, however, only with an assignment sheet. The daily revelation of what they have to do tomorrow permits the student no flexibility in his planning.

Assignment Length

In high school, most students take about four academic subjects at a time. If each of these academic subjects *averages* 30 minutes of homework per night for the *average* student (whatever

that is), most students will have about 2 hours of homework per night. This does not mean that assignments should always be structured to fill only 30 minutes per night. The night before a major test, a student may need to spend 2 hours on one subject. When the teacher is teaching mastery of a topic, some students may need to spend only a few minutes on homework for that class. Of course, if the student has assignment sheets, he can read all of his literature, history, or biology assignments for the week on Saturday afternoon if he wants to and leave time free for other things on weeknights. Stress to the students that the "average of 30 minutes" that he spends on a class needs to be 30 minutes of concentration, not 30 minutes of half-hearted study rendered useless by distractions.

Table TE-2 shows a sample assignment sheet for the first chapter of *BIOLOGY for Christian Schools®*. The pace is possibly a bit slower than normal because both teacher and students are getting "warmed up." Table TE-2 also contains an analysis of the assignment sheet which should be helpful in working out other assignment sheets. Within the 10 class days of the assignment sheet shown, students should be expected to spend 5 hours on biology homework. (It is assumed that if no homework is assigned on Wednesday evening, they will do extra work on the other nights or over the weekend.) Since an average student should be able to read (not necessarily master or memorize) an *actual page* (a page with type from top to bottom) in the text in about 5 minutes, each of the reading assignments can be completed within 30 minutes. The reading assignments will be completed, at this rate, in about 2 hours. Assume that each student spends about half an hour outside of class preparing or finishing each laboratory exercise. He will have to spend 3 hours either reading or working on assignments for biology and will have about 2 hours of this time left to spend on study, review, and mastering special points.

Of course, students who have poor academic backgrounds or abilities may need to spend considerably more than 5 hours in 2 weeks, and gifted students who "know the academic ropes" can probably do the expected work in considerably less than 5 hours. Adjusting the assignment length for either of these special groups does an injustice to the other group. Prepare assignments for the average student.

Using Review and Thought Questions

The Review Questions in each chapter are designed as a guide for the students (see *Introduction for the Student,* p. ix). If a student is able to answer these questions adequately, he should be able to do well on the test. These questions deal with concepts and principles as well as with text material.

One of the easiest assignments to make is to have the students read a chapter and write out the answers to the Review Questions. This approach is a gross misuse of these questions, and it easily degenerates into a busy-work assignment. For the intelligent student, it is a waste of time. For the average student, it can easily become a routine, mechanical task that requires no real understanding. For the poor student, such an assignment may be profitable, but if it is not carefully done, it becomes an impossible burden–an end in itself rather than a step toward the goal of knowing the material.

One excellent use of the Review Questions is in-class review. Games using these questions can be useful. Another use would be to give the poorer student an achievable goal. If he scores a certain level on a test (a D or F), have him write out and hand in the answers to the questions for the sections before the next test. If he gets a C on that test, he does not have to write the answers to the questions on the next unit. This can encourage the students to use the questions wisely; however, take care to stress the positive values (learn, get good grades, please the Lord in preparation) of doing this and not the negative side ("I *have to* write out the answers to the questions").

Some of the Thought Questions are rather difficult, so carefully screen them before assigning them as written work. Most of them were not intended to be written out, and a poor student could become very frustrated with some of the questions. The Thought Questions were designed to be discussed in class. It is wise to call attention to the more difficult Thought Questions and ask the students to prepare an answer to be discussed the next day in class. Some of the questions will not require such extensive preparation. The Thought Questions can also guide in the preparation of class activities. If these topics are covered during class discussions, it is reasonable to assume that the principles basic to biology are being covered.

Five-point Reading Quiz

Students can build up tension and a negative attitude if they face the possibility of a pop quiz any day they come to class. However, not having occasional pop quizzes to "check on" high school students and encourage them to keep up with their work is just about as bad as not quizzing at all. One successful method of checking up on students but not overburdening them is to limit the times at which such quizzes will be given. In using *BIOLOGY for Christian Schools,* for example, tell students that they will have quizzes only when they finish a chapter section. Whenever the assignment sheet tells them to "finish Chapter XX," they should prepare for a quiz, even though they may not have one. This normally will happen about twice a week, which is far better than daily!

If the quiz is going to determine if the students have read the assigned material, it must cover material which has not yet been presented in class. The students, if they are to do well on this type of quiz, must be able to pick out quickly from the reading assignment the material they may be tested over and should be able to master it on their own.

One successful method is the five-point reading quiz. First, list several Biological Terms from the chapter on the overhead projector or blackboard. Assign each word a letter. Then prepare a list of four definitions (not directly from the text). Rather than always using definitions, sometimes give examples, ask for a word that has the opposite meaning, or ask for a word that is the same as one of the terms. Read these statements aloud and have the students pick from the list the proper word and write its letter on a half sheet of paper. The fifth question is always "Have you read Chapter X thoroughly?" (Define "thoroughly" the first time this question is used.) It is possible for a student to get the first four correct (using the glossary and some common sense) without reading the chapter. It is also possible for a poor student to get the first four wrong and the last one right. That, however, should not happen often. Once even the poorest student catches on to how the five-point reading quiz works, he can prepare for it easily. When recording the quiz grades, make some mark to show if the student has missed question five. Use this as a subjective analysis of a student's effort to keep up with assignments. Parents also find such data "interesting" when progress reports must be given.

Some educators may argue that this type of quiz puts undue emphasis on terms and inadequate emphasis on principles. Terms, however, are something that most tenth graders can master easily; principles often require thought and direction that the student is not able to muster by himself. After discussing them in class, reasoning them out, and working with them, principles should be a significant section of the students' evaluation. The primary thrust of the five-point reading quiz, however, is to encourage the student to read his assignment and put more into the reading than just passing it in front of his eyes. It may not be a foolproof system, but it does work.

Other Forms of Evaluation

The *diagnostic quiz* can be given at the beginning of a section of material to determine how much students know about a subject, either to direct the teaching or to encourage the students to pay attention to the material. It can also be given at the end of a class activity, before the students study on their own; the result will help them direct their study. Do not count these quizzes as part of the students' grade. Diagnostic quizzes are, by definition, tools to evaluate areas other than student progress.

In biology class it is often advisable to have *announced quizzes*. Announced quizzes should stress important points and encourage mastering material. For example, announcing that there will be a quiz covering mitosis and meiosis and emphasizing comparison of the two will force students to study these two important concepts before the unit test date. This will be especially valuable if the test does not follow soon after the class discussion. In addition, a thorough understanding of these concepts is crucial to understanding the remainder of Chapters 5 and 6 as well as many later concepts. Since the student has a chance to prepare for these quizzes, they can and should be counted as part of his grade.

A unit test should be given about every two weeks. In a survey course, less than five or six class periods' work is not enough material for a test, and a unit longer than ten class periods will contain so much material that the student will not be able to prepare adequately for the test. It is wise to have longer units when the material warrants a level of mastery requiring a good deal of class time on a particular subject and shorter units when mastery has not been a key issue.

In a survey course in which a mass of material is presented and students are not expected to master all of it, tests should be broad in scope. A student should not be expected to get 100% of the items correct. A student may have worked on and mastered some of the concepts within the unit, and he may have deleted a few which he felt were unimportant but which appeared on the test. In a survey course, reward students with grades based on how much they learn. Do not expect complete mastery of *all* the material. A strict grading scale (e.g., 94 to 100% = A) is not advisable for a survey class. The hard-and-fast grading scale is best used in the class stressing mastery. (The *BIOLOGY for Christian Schools Testbank®* contains a collection of questions for each chapter from which a teacher can select ones that cover the material he has covered and stressed.)

Grade laboratory work to keep it out of the realm of play and in the realm of learning. The grading system should make getting an A difficult but getting a B or C easy. In order for a student to get a D or F, he would have to ignore the assignment.

Assigning weight to the various grades obtained in the course of a grading period requires careful balancing. A reading quiz should not be given the same weight as a test. It is a good idea to lump together all the quiz grades for a grading period and count them as the equivalent of a test grade (or perhaps half a test) and do the same for the lab grades. These two types of grades then have a cumulative significance, but an individual quiz or lab cannot ruin a student's grade in the course.

Other Assignments

Although a science fair project is often valuable for many students, most term papers, research papers, or similar assignments are not in keeping with the goals of a high school survey course. This type of course emphasizes a broad range of material, not the in-depth study of a particular area. If you do choose to make this kind of assignment, make the assignment months in advance and check periodically on student progress. Set aside one assignment per week if this type of project is included. It will slow class progress by about 20%; thus, requiring a major project means eliminating material from the course.

Although special cases deserve some form of extra credit, some students are specialists in the extra-credit assignment and never do an acceptable job on regular assignments. They pass the course, not by doing what was expected of everyone in the class but only because of the special burst of extra-credit work. If you give extra credit, it is recommended that it be of the type that must be earned a little at a time and cannot provide a major thrust to greatly improve a grade at the end of the semester. This lesson in faithfulness and diligence is valuable. Bonus work (such as a few extra questions on a test), as long as it is only a few points at a time and can be earned only through course work, is good motivation for many students.

How to Use This Teacher's Edition

For each chapter in the student text, the Teacher's Edition contains the following:

- A list of objectives
- A suggested **Time Frame**
- A brief description of **Laboratory Activities** available in *Laboratory Manual: BIOLOGY for Christian Schools®* designed to help the teacher in planning and scheduling
- An overview of the chapter, including a discussion of various teaching techniques to be considered (and some to be avoided)
- An overview of each chapter section
- The marginal materials (etymologies and footnotes) of the student edition
- A collection of teaching notes (in the margin), including the following material:
  - additional biological information (interesting or unusual facts)
  - additional examples
  - additional explanation of a biological point or concept
  - further Scriptural or spiritual considerations than are presented in the text
  - suggestions regarding materials to be omitted or skimmed
  - suggestions regarding which material should be stressed
  - notes regarding the use of visuals contained in *BIOLOGY for Christian Schools® Visuals Packet*
  - references to other places in the text that deal with related materials
  - suggestions of teaching techniques and aids appropriate for particular chapter content
- Answers to Review and Thought Questions

Most teachers will find having these items on (or near) the student pages useful.

At the front of each of the two volumes of this Teacher's Edition are the tables TE-1 through TE-3 as well as the *Commonly Used Combining Forms* section. At the end of each of the two volumes are the Appendixes, the Glossary, and the Index. These sections are included in both volumes so that they can be used even when only one volume is used in class.

Guidelines for Planning a Survey Course in Biology

Chapter	Time Frame*	Laboratory Activities	Testing
1–The Science of Life and the God of Life 1A–God and Science 1B–The Scientific Method 1C–Biology and the Study of Life	Content: 4-7 periods Labs: 1-3 periods Class Time: 2 weeks	**1A** *The Scientific Method*–$1\frac{1}{2}$ periods. Done as a demonstration with a section of laboratory activity and computing results as homework. **1B** *The Microscope*–1 period. Select sections to develop needed techniques.	Immediately following chapter.
2–The Chemistry of Life 2A–Basic Chemistry 2B–Organic Chemistry	Content: 4-6 periods Labs: $\frac{1}{2}$ period Class Time: 1 week	**2** *Osmosis and Digestion*–10 min. demonstration at the beginning of class; observe periodically during remainder of class.	Immediately following chapter.
3–Cytology Part I: Introduction to Cells 3A–The Structure of Cells 3B–The Living State of Cells	Content: 3-5 periods Labs: 1-2 periods Class Time: 1 week	**3A** *Basic Cytology*– $\frac{1}{2}$-1 period, depending upon what is omitted. **3B** *Cellular Structure and Processes*– $\frac{1}{2}$-1 period, depending on what is omitted. Consider combining sections of 3A and 3B for a 1-period exercise.	Immediately following chapter, or combine Ch. 3 and 4 for a unit of $1\frac{1}{2}$-2 weeks with test following.
4–Cytology Part II: Cellular Processes 4A–Cellular Energy 4B–Cellular Metabolism and Protein Synthesis	Content: 2-6 periods Labs: 1 period Class Time: 1 week	**4** *Photosynthesis*–1 period. Best done as demonstration. Involves measuring the rate of photosynthesis being carried on by a water plant under different conditions. Lab takes 10 min. to set up and should be observed periodically for about 1 hour.	Immediately following chapter, or see Ch. 3.
5–The Continuity of Life Part I: Genetics 5A–Genes and Chromosomes 5B–Basic Genetics	Content: 3-6 periods Labs: 1 period, several homework assignments Class Time: $1\frac{1}{2}$ weeks	**5A** *Mitosis and Meiosis*–1 period. **5B** *Genetics: Parts I-V*–Homework assignments, possibly reviewed in class.	Immediately following chapter, or combine Ch. 5 and 6 for a 2-week unit with test following.

*The information given in the Time Frame column is to help teachers plan a survey biology course using the entire text. Omitting certain sections of the text will allow more time to be spent on other sections.

Content: The number indicates how many 45-50 min. periods are needed to cover just the chapter content in direct presentation format (e.g., lecture or demonstration). The minimum time does not include laboratory activities, tests, quizzes, or review, nor does it permit indirect teaching methods, more thorough coverage, or teaching less academically prepared students. The maximum number of periods is just over 140. (Normally a school year is 180 class days. Many days, however, are unusable for teaching.) Some units will be covered in the minimum number of days; others may take longer than the maximum, especially when labs and tests are added. Most units will fall somewhere in between.

Using *Biology for Christian Schools*® (Table TE-1)

Facet Recommendations	Suggestions
1A-1 *How God Communicates to Man*–Students read; cover in 10-15 min. in class (devotional). **1B-1** *Spontaneous Generation and the Scientific Method*–Students read; cover in $\frac{1}{2}$ period in class. Cover on test. **1C-1** *Biological Research Techniques*–Possible to omit. Students read; cover in 10 min. in class. Omit from test.	**1A-1** Stress *Classification of Truth* (p. 12). Be sure a Christian philosophy of science is explained. **1B-1** Box (p. 17) can be on test. Stress *Limitations of Science* (p. 18). If behind, omit *Pure and Applied Science* (p. 26). Be sure to add practical development of Christian philosophy of science (pp. 25, 27-29). **1C-1** Survey *Biological Measurements* (pp. 34-35). Detailed knowledge of these is not essential for most high school students. Be sure to stress *Attributes of Life* and how a microscope works.
2A-1 *Acids, Bases, and Buffers*–Cover thoroughly in 30-50 min. **2A-2** *Solutions, Suspensions, and Colloids*–Cover thoroughly in 20-30 min. **2B-1** *Enzymes–The Keys to Life*–Cover thoroughly in 20-30 min.	**2A** If students are well versed in basic chemistry, this chapter can be covered quickly. The Facets are vitally important to an understanding of biological principles. Cover them thoroughly. **2B** This is new material to most students, and it is crucial to understanding other parts of the text. Carefully introduce this material, but do not become bogged down with formulas and details.
	3A Boxes to stress: *Cellular Functions and Processes* (p. 70), *Levels of Cellular Organization* (p. 71), and *Membranes Found in Cells* (p. 74). Boxes to skim: *Plant Cell Walls* (p. 73) and *Cytoskeletons* (p. 79). Be sure to survey cellular structures, but do not teach for mastery.
4A-1 *A Closer Look at Photosynthesis*–Optional **4A-2** *A Closer Look at Aerobic Cellular Respiration*–Optional **4B-1** *Interrelated Metabolism–Living Things Change Things*–Possible to omit. Students read; cover in 20-30 min. in class.	**4A** Thoroughly cover ATP (p. 91). Here one may opt to cover photosynthesis and cellular respiration very briefly (as presented in the text) or with varying amounts of detail. The *Closer Look* sections (pp. 94-95, 98-99) may be discussed in class briefly and tested over lightly (recommended) or omitted from testing. They can also serve as a detailed study. Be sure to point out cellular fermentations. **4B** Cover protein synthesis carefully. Omit box on the *Manufacture of RNA* (p. 104) and *Mitochondria Genetic Code* (p. 108). Thoroughly cover metabolism, homeostasis, and the *Cellular Digestion* box (p. 110).
5A-1 *Clones and Cloning*–Students read; cover in 20-30 min. in class. Cover on test. **5B-1** *The Key to Genetics–Fruit Flies*–Students read; cover in 10-20 min. in class. Possible to omit. **5B-2** *The Royal Disease–Hemophilia*–Students read; cover in 10-20 min. in class. Good example in text. Also covered in laboratory activity.	**5A** Proceed carefully, stressing material that will be needed to understand material in next chapters. Contrast mitosis and meiosis. Omit plant meiosis box (p. 123). **5B** Although this section requires using mastery techniques, the ability to work genetics problems helps few students in most walks of life; they need not master this. Consider skimming or omitting *Dihybrid Crosses* and *Multiple Gene Interaction* (pp. 134-36). The rest of the chapter should be taught thoroughly.

Labs: Specifies the number of class periods needed to do the activities available in the Laboratory Manual. This does not include time spent out of class for student research or preparation. Many of these labs can be done as demonstrations, thereby reducing time. The minimum number of periods is just over 30; the maximum is 45. It is not recommended that every laboratory activity be done. For suggestions, see Laboratory Manual, Teacher's Edition.

Class Time: Indicates the amount of class time to the nearest $\frac{1}{2}$ week that should be budgeted to this material, including tests and laboratory activities. Not every unit should be covered precisely in the time indicated. The total number of weeks in this chart is 33. (Most schools have 35-36 weeks in a school year.)

Chapter	Time Frame	Laboratory Activities	Testing
6–The Continuity of Life Part II: Advanced Genetics 6A–Chromosome and Gene Changes 6B–Modern Genetics	Content: 2-4 periods Labs: $\frac{1}{2}$ period Class Time: 1 week	**6** *Genetic Research*–Students find articles and give reports on current genetic research.	Immediately following chapter, or see Ch. 5. (Unless Ch. 6 is covered in detail, it is recommended Ch. 6 be combined with Ch. 5 for testing.)
7–The History of Life 7A–Theories of Evolution 7B–Biblical Creationism 7C–Theories of Biological Evolution	Content: 5-8 periods Labs: None Class Time: $1\frac{1}{2}$ weeks	**7** *Creationism: My Beliefs and Defense*–Students write short essays defending creationism.	Immediately following chapter, or combine Ch. 7 and 8 for a $2\frac{1}{2}$-week unit with test following.
8–The Classification of Organisms 8A–The Necessity of Classifying 8B–The Species and the Kind	Content: 2-3 periods Labs: 1 period Class Time: 1 week	**8** *The Use of Biological Keys*–$\frac{1}{2}$-1 period, depending on the number students are assigned to identify.	Immediately following chapter, or see Ch. 7.
9–Microbiology Part I: The Kingdom Monera and the Viruses 9A–Bacteria and Similar Organisms 9B–Viruses 9C–Diseases and Disorders	Content: 4-8 periods Labs: 1 period Class Time: $1\frac{1}{2}$ weeks	**9A** *Bacterial Basics*–Demonstration taking 20-30 min. of class time. **9B** *Bacteria and Antibiotics*–Demonstration taking 20-30 min. of class. Consider combining these exercises.	Immediately following chapter.
10–Microbiology Part II: The Kingdom Protista 10A–The Protozoans 10B–The Algae	Content: 2-4 periods Labs: 2-4 periods Class Time: $1\frac{1}{2}$ weeks	**10A** *The Protozoans*–1-2 periods. **10B** *The Algae*–1-2 periods. Consider combining these exercises and omitting sections to form a 3-period activity.	Immediately following chapter, or combine Ch. 10 and 11 for a 2-week unit with test following.

Facet Recommendations	Suggestions
6A-1 *Human Gene Mutations–Treatments and Cures*–Students read; cover in 10-20 min. in class. Cover on test (optional). **6A-2** *Genetic Engineering*–Students read; cover in 20-30 min. in class. Although optional, this Facet is recommended. Much scientific work will be done in this area, and students will need to make many significant decisions.	**6A** Survey this material quickly. *Man's Use of Polyploids* (p. 145) makes good illustrative material for other sections of the chapter. The *Normal Variations* box (p. 153) will be interesting to advanced students. If students ask about this material, it should be discussed; if not, consider omitting it. **6B** A good place for class discussion rather than a lecture. (Discussions are time consuming but do more to change opinions and positions than other forms of teaching.)
7B-1 *Noah's Ark and the Animals*–Students read; cover in 10-20 min. in class. Cover on test. **7C-1** *Anthropology*–Students read; cover in 10-20 min. in class. Cover on test (optional). **7C-2** *Arguments That Have Been Used to Support Evolutionary Theory*–Although most of these arguments are defunct, they often appear in slightly altered forms. Students should be aware of them. Students read; cover in 10-30 min. in class. Cover on test.	**7A** Cover this chapter thoroughly. Be sure students know what it means to be a creationist. Cover thoroughly *The Results of an Evolutionary Philosophy* box (p. 171) and the *Theistic Evolution* box (p. 172). Be sure a good foundation for future discussion is laid while covering this section. **7B** The box *Scriptures and the Gap Theory* (p. 173) is optional, depending on how much controversy this has in your area. Cover thoroughly *Other Indications of the Canopy Theory* (p. 176), *Reasons the Deluge Was Universal* (p. 180), and *Dating Methods That Suggest Relatively Recent Dates for the Age of the Earth* (p. 188). Skim or omit the *Radio Carbon Dating Method* box (p. 180). **7C** Be sure students understand evolutionary theory and the creationist arguments against the evolutionary position. If necessary, omit *Lamarck's Theory and Blind Cave Fish* (p. 194). Cover thoroughly the other boxes and the text.
8A-1 *"What Is It?" The Identification of Organisms Using Biological Keys*–Required for Laboratory Activity 8A. Interesting, but possible to omit.	**8A** Cover thoroughly, but quickly. Do not omit the *Varieties* box (p. 218). **8B** Cover thoroughly, but quickly. Both boxes should be covered, since they deal with commonly discussed matters.
9A-1 *The Uses of Bacteria–Past, Present, and Future*–Students read; cover as examples in class. Cover on test (optional). **9A-2** *Controlling Bacteria*–Optional. Students read; cover in 10-20 min. in class. **9B-1** *Smallpox–A Plague of the Past*–Students read; cover in class. Cover on test. **9C-1** *Aging and Death*–Students read; cover in 10-30 min. in class. Cover on test (optional).	**9A** Cover chapter quickly. The *Pasteurization* box (p. 230) can be easily covered. Skim quickly the *Transfer of Genetic Material in Bacteria* box (p. 232) and the *Rickettsias, Spirochetes, and Mycoplasma* box (p. 234). **9B** Cover thoroughly. Do not test over page 243 (or select a few to test over). **9C** Survey quickly. Do not omit *Kinds of Toxins* box (p. 246). Read the *Leprosy* box (p. 247). Do not test over pages 250-51 (or select a few to test over). Read boxes on *Cancer* (pp. 254, 258).
10B *The Algae Phyla*–Select algae for students to study based on laboratory activities chosen.	**10A** Survey quickly. Choose laboratory exercises to reinforce what students are to learn. Select *Other Protozoans* (p. 262) and *Protozoan Diseases* (p. 266) to illustrate phyla characteristics students need to learn. **10B** Survey quickly. Choose algae examples to reinforce what students are to learn. Spend little time in lecture and much in laboratory work.

Chapter	Time Frame	Laboratory Activities	Testing
11–The Kingdom Fungi	Content: 1-2 periods Labs: 1-1½ periods Class Time: ½ week	**11** *The Fungi*–1 period. Select fewer parts of exercise to reduce time. Consider combining this activity with Labs 10A and 10B for a major exercise if combining Ch. 10 and 11.	Immediately following chapter, or see Ch. 10.
12–Botany Part I: The Plant Kingdom and Plant Structure 12A–Plant Classification 12B–Plant Anatomy	Content: 3-5 periods Labs: 2 periods Class Time: 1½ weeks	**12A** *Plant Identification*–1 period. Decrease number of plants to shorten activity. **12B** *Plant Organs*–1 period; can be shortened.	Immediately following chapter, or combine Ch. 12 and 13 for a 2-week unit with test following.
13–Botany Part II: The Life Processes of Plants 13A–Plant Physiology 13B–Plant Reproduction	Content: 3-4 periods Labs: 1 period Class Time: 1 week	**13** *Flowers, Fruits, and Seeds*–1 period, shortened by doing sections as demonstrations.	Immediately following chapter, or see Ch. 12.
14–Zoology Part I: The Invertebrates 14A–Introduction to the Animal Kingdom 14B–Phyla Porifera and Cnidaria 14C–The Worms 14D–Other Invertebrates	Content: 4-7 periods Labs: 3 periods Class Time: 1½ weeks	**14A** *Porifera*– ½ period observing sponges. **14B** *Cnidaria*– ½ period observing hydra (combine with 14A). **14C** *Worms 1: Platyhelminthes and Nematoda*– ½ period observing Planaria and *Ascaris*. **14D** *Worms 2: Annelida*–1-2 periods observing live earthworms and dissecting a preserved one.	Immediately following chapter. By omitting material, Ch. 14 could be combined with Ch. 15 for a 2-week unit with test following.
15–Zoology Part II: The Arthropods 15A–Introduction to Arthropods 15B–Class Insecta	Content: 2-4 periods Labs: 2-3 periods Class Time: 1½ weeks	**15A** *Malacostracans*–1-2 periods. **15B** *Grasshoppers*– ½ period observing grasshoppers. **15C** *Insect Orders*– ½ period observing insects. Oral reports add an additional period.	Immediately following chapter, or see Ch. 14.

Facet Recommendations	Suggestions
11A-1 *Edible Fungi–Delicious or Deadly*–Students read; cover in 5-10 min. in class or omit.	**11** Survey quickly. Omit *Rust and Smuts: Plant Parasites* (p. 285) if behind. Skim other boxes. Choose laboratory examples students are to learn for testing purposes; omit the others.
12B-1 *Modified Plant Parts*–Students read; cover Facet examples when discussing leaves, roots, and stems. Cover on test.	**12A** Survey; do not stress mastery of life cycles, terms, or structures. The boxes *Heterotrophic Plants* (p. 289), *Liverworts* (p. 291), *Minor Seedless Plant Phyla* (p. 293), and *Minor Gymnosperm Phyla* (p. 296) contain examples of characteristics of unusual plants. Omit, or use to fill out the classification chart. Read *The Cedars of Lebanon* and *Useful Gymnosperms* boxes (pp. 294-95) as interesting sidelights. **12B** *Annuals, Biennials, and Perennials* (p. 299) and *Kinds of Wood* (p. 311) contain definitions of common, useful terms; do not omit. Read and survey quickly *Falling Leaves*. Omit *Plant Pigments* (p. 304) if time is limited. *Girdling* (p. 313) offers a physiological explanation of a common occurrence.
13A-1 *Plants that Catch Insects*–Students read; cover in 5-10 min. in class. Cover on test. **13A-2** *Dormancy in Plants*–Students read; cover in 10-15 min. in class. Cover on test. **13B-1** *Grafting and Budding*–Students read; cover in 10-15 min. in class. Cover on test.	**13A** Cover this chapter as a brief survey. *Guttation* and *Nastic Movements* (p. 318) are interesting examples of how plants use water. Cover quickly. The *Organic Gardening* box (p. 322) is an interesting sidelight. **13B** The *Plant Fertilization* box (p. 332) is for advanced classes. The *Fruits* box is best covered as part of the laboratory activity.
14C-1 *Parasitic Worms in Humans*–Students read; cover Facet examples when discussing worm groups. Select examples for testing.	**14A** Cover thoroughly. Foundation for the next four chapters. Note *Animal Classification and Evolution* (p. 339) is a review. Do not memorize numbers on page 440. **14B** Cover quickly *The Use of Sponges* (p. 343) and *Other Cnidarians* (p. 346). Do not omit *Jellyfish*; cover quickly. **14C** Cover in more detail than 14B. These organisms affect humans more directly. Skim *Earthworms and the Soil* (p. 355) and *Other Segmented Worms* (p. 357). **14D** Briefly mention these two phyla. Consider having students read the text but giving them a handout of material to know for testing. Cover *Mollusca* in 15 min. and *Echinoderms* in 10 min. What cannot be covered in that time, omit.
15A-1 *Spider Webs*–Students read; cover in 10-15 min. in class. Possible to omit. **15B-1** *Insect Survival*–Students read; cover thoroughly in class. Cover on test. **15B-2** *Control of Insects*–Students read; cover thoroughly in class. Cover on test.	**15A** Cover first of chapter thoroughly. If dissecting crayfish, skim *Malacostracans*. Cover *Other Malacostracans* (p. 368), *Dangerous Spiders* (p. 370), and *Centipedes and Millipedes* (p. 372) quickly. **15B** Cover insect characteristics thoroughly. Consider omitting the insect orders (pp. 380-82, 386-87), or select certain orders and examples to know.

Chapter	Time Frame	Laboratory Activities	Testing
16–Zoology Part III: The Ectothermic Vertebrates 16A–Phylum Chordata 16B–Class Osteichthyes: The Fish 16C–Class Amphibia: The Amphibians 16D–Class Reptilia: The Reptiles	Content: 5-8 periods Labs: 2-3 periods Class Time: 2 weeks	**16A** *Observations of a Bony Fish*–$\frac{1}{2}$-1 period observing preserved and live fish. **16B** *Dissection of a Bony Fish*–1-2 periods. Consider combining Labs 16A and 16B for a 2-period lab.	Immediately following chapter.
17–Zoology Part IV: The Endothermic Vertebrates 17A–Class Aves: The Birds 17B–Class Mammalia: The Mammals	Content: 4-5 periods Labs: 1 period Class Time: 1 week	**17** *Birds and Mammals*–1 period observing feathers, fur, and skeletons (shorter if sections omitted).	Immediately following chapter.
18–Ecology 18A–The Ecosystem 18B–The Biosphere 18C–Man in the Biosphere	Content: 4-8 periods Labs: 1-2 periods Class Time: 2 weeks	**18** *Succession and Pollution*– $\frac{1}{2}$ period to set up microcosms; observation 10-20 min. per day for several days.	Immediately following chapter.
19–Introduction to Human Anatomy and Physiology 19A–What is a Human? 19B–The Integumentary System 19C–The Skeletal System 19D–The Muscular System	Content: 4-8 periods Labs: 2-3 periods Class Time: $1\frac{1}{2}$ weeks	**19A** *Readings on the Human Body*–Out-of-class research project. **19B** *The Human Body and the Skeletal System*– $\frac{1}{2}$-period lab with homework. **19C** *The Human Integumentary and Muscular Systems*– $\frac{1}{2}$-period lab with homework.	Immediately following chapter.
20–Incoming Substances 20A–The Respiratory System 20B–The Digestive System	Content: 3-6 periods Labs: 2-4 periods Class Time: 1 week	**20A** *Human Respiratory System*–$\frac{1}{2}$-period demonstration with homework. **20B** *Human Digestive System*–Homework.	Immediately following chapter.

Facet Recommendations	Suggestions
16B-1 *Jawless Fish–Class Agnatha*–Students read; cover in 10-15 min. in class. Cover on test. **16B-2** *Cartilaginous Fish–Class Chondrichthyes*–Students read; cover in 10-15 min. in class. Cover on test. **16D-1** *Dinosaurs*–Students read; cover in 10 min. in class. Cover on test. Select examples to cover on test. **16D-2** *Poisonous Snakes*–Students read; cover in 10 min. in class. Cover on test. Do not have students learn foreign examples.	**16A** Cover thoroughly. Foundation for next two chapters. Omit *Classification within Chordates* (p. 389). Skim *Supposed Evolution of Vertebrate Reproduction*. **16B** Cover section quickly. Cover *The Fins of a Fish* (p. 396) as part of Lab 16A. Skim or omit *Salt-water and Freshwater Fish* (p. 402) and *Unique Fish* (p. 403). **16C** Omit *American Frogs and Toads* (p. 406). Cover *Frog and Toad Reproduction* (p. 410) thoroughly. Postpone coverage of frog anatomy (pp. 407-11) to end of year. See Ch. 16 notes. **16D** Cover first of chapter thoroughly; skim examples (pp. 417-22). Consider omitting *Tuatara* (p. 417), *Lizards* (p. 420), and *Turtles and Tortoises* (p. 421). Substitute local examples.
17A-1 *Types of Birds*–Students read; cover in 30-50 min. Cover on test. Possible to omit. **17B-1** *Hooved Animals in the Bible*–Students read; cover in 20-30 minutes. Cover on test.	**17A** Cover chapter quickly. This is review for most students. Use boxes about bird wings (p. 425), feet (p. 426), and nests (p. 433) as chapter-content examples or omit. **17B** Cover boxes about mammal orders, *Monotremes* (p. 442), *Marsupials* (pp. 444-45) on test. Skim boxes *Biblical Rodents* (p. 443), *Opossum* (p. 443), *The Lion in the Bible* (p. 446).
18A-1 *Biotic Community Relations*–Students read; cover in 10-15 min. Cover on test. **18B-1** *Major Biomes of the World*–Students read; cover in 20 min. to 2 periods. Possible to omit. **18B-2** *Succession*–Students read; cover in 20 min. Cover on test. **18C-1** *Animal Rights and Wrongs*–Students read; cover in 20-40 min. Cover on test.	**18A** Cover the principles thoroughly. Do not omit the *Detritus Food Chain* (p. 464). Skim *The Rabbit and Its Cud* (p. 465). **18B** Skim, but do not omit *The Oxygen and Carbon Cycles* (p. 469) and *The Nitrogen Cycle* (p. 470). Use *Principles Regarding Limiting Factors* (p. 472) as a summary/review of the text. Skim the *Biomes* Facet. Cover thoroughly the *Succession* and *Animal Rights and Wrongs* (p. 495) Facets. **18C** Cover *"Useful" Pollutants* thoroughly. Skim *Recycling* (p. 494).
19A-1 *Human Tissues*–Students read; cover in 10-30 min. Cover on test. Possible to omit. **19C-1** *The Human Skeleton*–Students read; cover bones in lecture. Select examples to cover on test. Possible to omit. **19D-1** *Human Muscles and Their Movement*–Students read; cover muscle actions and characteristics thoroughly. Select examples to cover on test. Possible to omit.	**19A** Cover the material in this section thoroughly. **19B** Cover this section quickly. Skim the boxes. **19D** Cover content quickly. Skim *Broken Bones* (p. 515), *Bone Growth* (p. 516), and *A Separate Plate* (p. 516). **19D** Cover content quickly. Teach *Types of Muscle Contractions* (p. 528), and skim *Big Muscles, Little Muscles* (p. 529).
20A-1 *Tobacco Smoking*–Students read; cover in 10-15 min. in class. Cover on test. **20B-1** *Minerals and Vitamins*–Students read; cover in 10-15 minutes in class. Cover on test. Do not have students learn minerals or vitamins.	**20A** Cover anatomy quickly. Skim *The Voice* (p. 532), *The Mechanics of Breathing*, and *Carbon Monoxide Poisoning* (p. 535). Teach respiration thoroughly. **20B** Cover the organs of the digestive system quickly. Teach *Tooth Decay* (p. 540) and the *Walls of the Alimentary Canal* (p. 541) quickly. Spend more time on foods and digestion; skim details; get the principles across.

Chapter	Time Frame	Laboratory Activities	Testing
21–Internal Transport 21A–The Circulatory System 21B–The Lymphatic System and Immunity 21C–The Excretory System	Content: 6-8 periods Labs: 1-2 periods Class Time: 2 weeks	**21A** *Blood*– ½ period. Ideal for demonstration. **21B** *Human Circulation*–1 period (less as demonstration).	Immediately following chapter.
22–Control Part I: The Nervous System 22A–The Nervous System 22B–The Sense Organs	Content: 3-5 periods Labs: 1-2 periods Class Time: 1 week	**22A** *Human Reflexes*– ½ period (less as demonstration). **22B** *The Minor Senses*– ½ period (less as demonstration). **22C** *The Eye and the Ear*– ½ period. Some parts students can do at home.	Immediately following chapter, or combine Ch. 22 and 23 for a 2-week unit with test following.
23–Control Part II: Hormones and the Human Mind 23A–The Endocrine System 23B–The Control of the Mind	Content: 3-5 periods Labs: 1 period Class Time: 1 week	**23** *Drugs in Our Culture*–An out-of-class research project.	Immediately following chapter, or see Ch. 22.
24–Human Reproduction 24A–The Reproductive System 24B–Human Relationships–A Christian Perspective	Content: 3-6 periods Labs: 1 period Class Time: 1 week	**24** *Chicken Embryology*–Interesting but difficult. Best done as demonstration. May take ½ a period, depending upon how it is done.	Immediately following chapter.
The Frog Lab	Labs: 4-5 periods Class Time: 1 week	**The Frog Lab** Laboratory Final Exam. Frog dissection.	During the Lab.

Facet Recommendations	Suggestions
21A-1 *Blood Transfusions and Blood Grouping*–Students read; cover briefly in class. Possible to omit. **21A-2** *Blood Pressure and Hypertension*–Students read; cover in 10-15 min. in class. Cover on test. **21B-1** *AIDS: Acquired Immune Deficiency Syndrome*–Students read; cover thoroughly. Cover on test. **21B-2** *Allergies and Tissue Rejection*–Students read; cover in 10-20 min. in class. Cover on test (optional). Possible to omit.	**21A** Cover thoroughly. Can omit *Blood Proteins* (p. 552) and *The Rh System* (p. 555). Cover quickly or use in Lab 21B *The Sounds of the Heart* (p. 557) and *The Pulse* (p. 562). Cover on test *The Electrocardiogram* (p. 560) and *The Heart Attack* (p. 561). **21B** Cover thoroughly. Skim *Lymphatic Organs* (p. 568) and the *Cold* (p. 575). Omit *Where Immunity Begins* (p. 573). Cover *Kinds of Immunity* (p. 575) thoroughly. **21C** Cover quickly. Read *Artificial Kidneys* (pp. 578) but omit from testing.
22A-1 *The Body on Automatic Pilot*–Students read; cover in 10-15 min. Cover minimally on test.	**22A** Cover the first of the section thoroughly and the end quickly. Cover thoroughly *The Reflex Arc* (p. 583). Omit *Glial Cells* (p. 584). Read *Lobes of the Cerebrum* (p. 585); cover in 5 min. in class; omit from test. **22B** Cover quickly. Read *Referred Pain* (p. 591) and *Deafness* (p. 593); cover minimally on test. Cover thoroughly *Eye Disorders* (p. 596).
23A-1 *Anabolic Steroids–Instant Muscle*–Students read; cover in 10-15 min. in class. Cover minimally on test. **23A-2** *Puberty and Maturity*–Students read; cover thoroughly in class. Cover minimally on test. **23B-1** *The Drug Alcohol*–Students read; cover in 10-15 min. in class. Cover minimally on test. **23B-2** *The Narcotics*–Students read; cover in 15-25 min. in class. Cover on test.	**23A** Cover this section thoroughly. Cover every box briefly or omit. Consider using *Diabetes Mellitus and Hypoglycemia* (p. 604) to illustrate main principles of the section. **23B** Cover this section thoroughly. Read *Dreaming to Forget* (p. 613), *Miraculous Healing* (p. 616), and *Physical Effects of Alcohol* (p. 617); cover in 5 min. in class. Cover minimally on test. Cover thoroughly *Good Drugs–Bad Drugs* (p. 619) as conclusion.
24B-1 *Sexually Transmitted Diseases*–Students read; cover in 10-20 min. in class. Cover minimally on test.	**24A** Cover this section thoroughly. Read *Circumcision* (p. 629) and *Cervical Cancer* (p. 631); cover in passing. Cover minimally on test. Cover quickly *The Newborn Baby* (p. 637). **24B** Cover this section thoroughly. Read *Syphillis and Gonorrhea–Two Common STDs* (p. 645); cover in passing. Cover minimally on test. Cover thoroughly *The Bible and Abortion* (p. 640) and *Homosexuality* (p. 646). Summarize euthanasia with *Should Treatment be Terminated?* (p. 642).
	Cover the end of Chapter 16C as students review human anatomy and physiology.

Sample Assignment

Day	Assignment[1]	Text[2] Pages	Actual[2] Pages	Estimated[3] Time to Complete Basic Assignment
Friday	Read Introduction (in class)	3	2 ½	12 min.
Monday	Read pp. 2-9	8	4	20 min.
Tuesday	Read Facet 1A-1 (pp. 10-11) Finish Ch. 1A	4	3	15 min.
Wednesday	Read pp. 14-18, 24	6	5	25 min.
Thursday	Finish Ch. 1B Read Facet 1B-1 (pp. 19-23)	9	6	30 min.
Friday	Prepare Lab 1A–*The Scientific Method*	Lab Manual: 4	1	30 min.
Monday	Read pp. 30-32 and *Biology Measurements* (pp. 34-35)	5	4	20 min.
Tuesday	Finish Ch. 1C, except Facet 1C-1 Lab 1A due today	6	4	20 min.
Wednesday	Prepare for Lab 1B–*The Microscope*	Lab Manual: 8	4	30 min.
Thursday	Read Facet 1C-1 (pp. 39-40)	2	1 ½	10 min.
Friday	Test 1 (Ch. 1 and Labs 1A and 1B) Lab 1B due by the end of class			

[1] To be completed by class time on the day indicated
[2] *Text pages* are the number of pages assigned for students to read; *actual pages* are the number of pages if the material were printed top margin to bottom margin on every page.
[3] Time is based on students' reading an actual page in 5 minutes. Study and review are separate.

Sheet (Table TE-2)

Assignment Notes
Many schools have evening opening services, and students will welcome not having homework in biology. Encourage students to start on Monday's assignment if they have time.
Tell students to expect longer assignments later. Warn of possible 5-point reading quiz on Tuesday.
Give a 5-point reading quiz; grade in class and discuss quiz philosophy. Encourage students to keep up with their assignments. Although it is not necessarily wise to give quizzes after a weekend, this type of quiz can work well because most students can prepare for it if they have read the material earlier; if they do not do well, they do not lose a great deal of points.
Moderate assignment, but warn students that the next assignment is heavy and they may want to work ahead; warn of possible 5-point reading quiz.
Do not give 5-point reading quiz the day after midweek prayer meeting. Explain tomorrow's assignment.
During class discussion explain what they are expected to hand in on Tuesday.
Let Tuesday's assignment go without comment. On Tuesday, stress that they need to do assignments whether or not the assignment is covered in class.
Give 5-point quiz. Have students review the assignment sheet. Remind them that the test is on Friday, the lab is tomorrow, Lab 1A is due today, and Lab 1B is due on Friday. Explain how to hand in lab assignments.
Lab day. Because most students will need to finish their lab work (write out answers to questions and label drawings), the next assignment is short.
Remind them of the test and Lab 1B, and give pointers for studying.

Sources for Biological Supplies and Teaching Aids (Table TE-3)

It is recommended that catalogs be requested from the following:

Boreal Laboratories
10 Oriskany Drive
Tonawanda, NY 14150

Carolina Biological Supply Co.
Burlington, NC 27215

Educational Images
P.O. Box 367
Lyons Falls, NY 13368

Fisher Scientific Company EMD
(Educational Materials Division)
4901 West LeMoyne Street
Chicago, IL 60651

Frey Scientific Co.
905 Hickory Lane
Mansfield, OH 44905

Hubbard
P.O. Box 104
1946 Raymond Drive
Northbrook, IL 60062

JLM Visuals
920 7th Avenue
Grafton, WI 53024

MacMillian Scientific Co., Inc.
8200 South Hoyne Avenue
Chicago, IL 60620

Nasco
901 Janesville Avenue
Fort Atkinson, WI 53538

National Geographic Society
Educational Services
P.O. Box 2895
Washington, D.C. 12277-9960

Sargen-Welch Scientific Company
7300 North Linder Avenue
Skokie, IL 60076

Schoolmasters Science
745 State Circle
Box 1941
Ann Arbor, MI 48106

Southwest Educational Enterprises
10711 Auldine
San Antonio, TX 78230

Commonly Used Combining Forms

Chapter 1A

bio-, -be, -bi, -bios
from Gk. *bios,* life (microbe, 7)

Other presentations in text: aerobic, 97; Amphibia, 404; antibiotics, 252; biodegradable, 492; biogenesis, 19; biology, 30; biome, 473; biopsy, 254; biosphere, 468; biosynthesis, 58; biotic, 574; symbiosis, 286

Other words: autobiography, *biochemistry**, biography, *biological, biologists,* bioluminescent, biomass, biophysics, biosatellite, bioscope

in-, il-, im-
from L. *in,* on (infusion, 7)

Other presentations in text: integument, 332; incisors, 438; incurrent, 342; inspiration, 533; invertebrate, 431

Other words: impose, inactive, *inborn,* incomplete, incorrect, incumbent, *incurable,* indefinite, indifferent, induce, infer, influx, *ingestion,* inorganic, inside, *invaginate,* insignificant, inspire

micro-
from Gk. *mikros,* small (microbe, 7)

Other presentations in text: microbiology, 226; microfilament, 79; micrometer, 35; micronucleus, 263; micropyle, 332; microscope, 33; microtubule, 79

Other words: *microbiology, Microcystis,* microcosm, microcurrents, microeconomics, microfile, microfilm, microorganism, microphone, microspore, *microstructure,* microwave

Chapter 1B

-logy
from Gk. *logos,* word, speech; English suffix for "study of" (biology, 30) (Concept: to know the words of a subject is to know the subject. *Logos* is the term used for "Word" in John 1:1. One knows the God of the Bible by studying His Word.)

Other presentations in text: anthropology, 199; cytology, 69; ecology, 453; embryology, 633; zoology, 337

Other words: analogy, apology, *bacteriology,* Christology, criminology, entymology, etymology, geology, herbitology, *histology, microbiology,* physiology, technology, theology

-genesis, gene-
from Gk. *genesis (genes),* birth, origin, born, beginning (biogenesis, 19)

Other presentations in text: benign, 251; eugenics, 160; fibrinogen, 556; homogenous, 55; oogenesis, 123; parthenogenesis, 143; pathogenic, 226; phylogenetic, 192; spermatogenesis, 123

Other words: degenerate, *gene, genealogy,* general, generate, generation, generic, genocide

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*Italicized words are either scientific names or words presented in the text but not in the etymology section.

hypo-
from Gk. *hypo,* beneath (hypothesis, 14)

Other presentations in text: hypoglycemia, 604; hypothalamus, 586; hypotonic, 84; hyposecretion, 600

Other words: hypochondriac, *hypocotyl,* hypocrisy, hypodermic, hypothetical

Chapter 1C

auto-
from Gk. *autos,* self (autoradiography, 40)

Other presentations in text: autonomic, 588; autophagy, 110; autotrophs, 90

Other words: autobiography, autocratic, autograph, automatic, automobile, autonomy, autopsy, *autosomes,* autotrophic

-centi-, -cent-
from L. *centum,* hundred (centimeter, 34)

Other presentations in text: centipede, 372

Other words: cent, centennial, centigrade, centurion, century, percent

chrom-
from Gk. *khroma,* color (chromatography, 40)
(See *chromatin* under Ch. 3A–Book 1, p. T25; Book 2, p. T19)

-graphy, -graph
from Gk. *graphein,* to write (micrograph, 37)

Other presentations in text: autoradiography, 40; topography, 186; ultrasonography, 39.

Other words: autograph, biography, geography, graph, paragraph, photography, sonography

-meter, metri-
from L. *metron,* measure (centimeter, 34)

Other presentations in text: asymmetrical, 340; isometric, 528; micrometer, 35; millimeter, 34; nanometer, 35

Other words: diameter, geometer, kilometer, *meter, metric,* metronome

milli-
from L. *mille,* thousand (millimeter, 34)

Other presentations in text: millipede, 372

Other words: *mile,* millenium, milligrams, *milliliters*
lion, milliseconds

-scope, -scopy
from Gk. *skopein,* to see (microscope, 33)

Other presentations in text: stethoscope, 557

Other words: periscope, *telescope*

ultra-
from L. *ultra,* beyond (ultrasonography, 39)

Other words: ultraconservative, ultrahigh (as in UHF), ultraliberal, ultramicroscope, ultramodern, ultrapure, ultrasensitive, ultrasonic, *ultraviolet*

Chapter 2A

chem-, chemic-, chemo-
from Gk. *khemia,* alchemy (hence, chemistry or chemicals) (chemistry, 42)

Other presentations in text: chemosynthesis, 96

Other words: chemoautotroph, *chemoreceptors,* chemosensory, chemosmosis, chemosurgery, *chemosynthetic,* chemotaxis, *chemotherapy,* chemurgy

dis-, dif-, di-
from L. *dis,* apart (diffusion, 51)

Other presentations in text: digestion, 70

Other words: different, differ, disaster, disapprove, *disease, disorder, dissect, dissemination,* dissension, diversion

electro-, electri-
from Gk. *elektron,* amber (Amber makes sparks when rubbed–usually refers to electrical energy.) (electron, 43)

Other presentations in text: electrocardiogram, 560; electroencephalogram, 256

Other words: electrician, electricity, electrify, electrochemical, electrocute, electronics

endo-, en-, em-
from Gk. *endon,* within, in (endoscopy, 40)

Other presentations in text: embolus, 557; embryology, 633; embryonic, 338; endocardium, 558; endocrine, 598; endodermis, 307; endoplasmic, 76; endoscope, 40; endoskeleton, 338; endosperm, 332; endospores, 230; endosteum, 514; endothermic, 53; endotoxins, 246; mesenchyme, 343; enzyme, 59

Other words: *dysentery,* embedded, encrypted, endanger, *endocarditis, endotoxins, endoscopes,* engulf, enjoy, entrails, entrance, *environment,* enter

e-, ex-, exo-, ef-, extra-
from L. *e-,* out (exothermic, 54)

Other presentations in text: efferent, 367; egestion, 70; everted, 362; evolve, 169; excretion, 70; excurrent, 342; expiration, 533; extracellular, 110

Other words: educate, effect, efficient, effort, elect, elongation, emit, evade, except, exclude, exit

homo-, homeo-, homoio,
from Gk. *homos,* same (homogenous, 55)

Other presentations in text: homeostasis, 83; homosexuality, 646; homozygous, 127

Other words: homeomorphism, homeotherm, homiletics, homocentric, homochromatic, homogenized, homoiothermic, *homologues, homologous,* homonym, homophobia, homopteran

-kinesis, kin-, cin-
from Gk. *kinein,* to move (kinetic, 50)

Other presentations in text: cytokinesis, 114; kinetosome, 81

Other words: cinema, excite, hyperkinetic, incite, kinesthesia, kinesthesiology, telekinesis

-oid
from Gk. *eiodos,* shape, form (colloid, 56)

Other presentations in text: diploid, 116; haploid, 121; rhizoid, 281.

Other words: *ameboid, arachnoid,* antropoid, *anueploid,* asteroid, *carotenoid, euglenoid, mongoloid,* ovoid, planetoid, *polyploid, rheumatoid, sesamoid,* spheroid, *steroid, tetraploid,* toxoid, trapezoid, *triploid, thyroid*

semi-
from L. *semis,* half (semipermeable, 52)

Other presentations in text: semilunar, 559

Other words: semiannual, semiarid, semicolon, semiconscious, semicircular, semiofficial, semiprivate, semiskilled semisolid

thermo-, -therm
from L. *therme,* heat (thermodynamics, 50)

Other presentations in text: ectothermic, 292; endothermic, 292

Other words: isotherm, nuclear, *thermal,* thermocline, thermocouple, thermoduric, thermoelectric, thermogram, thermoluminescence, thermolysis, *thermometer,* thermoperiodism, thermophilic, thermostable, thermostat

Chapter 2B

de-
from L. *de,* from, down from (dehydration, 62)

Other presentations in text: biodegradable, 492; deluge, 180; detoxified, 622

Other words: decision, decrease, defer, *degeneration, dehumanization,* deform, deodorant, *deoxyribonucleic,* depart, deplore, deprave, depreciation, *depressant*

di-, diplo-
from Gk. *di (diploos)* two (double) (disaccharide, 62)

Other presentations in text: dicotyledonae (dicot), 279; dihybrid, 134; diploid, 116; Diplopoda, 372; Diptera, 368

Other words: diameter, *diatoms,* dichloride, dichotomy, diorama, *dioxide, diphosphate, diplococcus,* diploma, divide

gluco-, glyc-
from Gk. *gleukos,* sweet new wine (sweet) (glucose, 61)

Other presentations in text: glycolysis, 98; hypoglycemia, 604

Other words: *glucoamylase, glucocorticoids,* glyceride, *glycerine, glycerol,* glycogen

hydro-
from Gk. *hudor,* water (dehydration, 62)

Other presentations in text: hydrolysis, 62; hydrophilic, 64; hydrophobic, 64; hydrotropism, 324

Other words: hydrant, hydraulic, hydrochloric, hydroelectric, *hydrogen,* hydroplane, hydroponics

lact-, lacto-
from L. *lac,* milk (lactose, 62)

Other presentations in text: prolactin, 603

Other words: *lactic acid, lactobacillus,* lactation, lactochrome, lactoprotein

lip-, lipo-
from Gk. *lipos,* fat (lipid, 63)

Other presentations in text: lipase, 547

Other words: bilipid, lipoid, lipofuscin, lipolysis, lipoprotein, liposuction, lipotropic, *phospholipid*

-lysis, -lyst
from Gk. *lusis,* to loosen, break apart (catalyst, 54)

Other presentation in text: hydrolysis, 62; cytolysis, 85; glycolysis, 98; lytic, 240; photolysis, 94; plasmolysis, 85

Other words: analysis, *catalysis, dialysis, paralysis, urinalysis*

mono-
from Gk. *monos,* single (monosaccharide, 61)

Other presentations in text: monocotyledoneae (monocot), 279; monohybrid, 127

Other words: monarch, monocle, *monoclonal, monocyte,* monogamy, monogram, mononucleus, monopoly, monorail, *monosomy,* monotheism, *monotreme, monoxide*

philo-, phil-, -philic
from Gk. *philos,* beloved, loving (hydrophilic, 64)

Other words: anglophilic, bibliophilic, lyophilic, philodendron, philology, philoprogenitive, *philosophy*

poly-
from Gk. *polas,* many (polysaccharide, 63)

Other presentations in text: polyp, 345; polypeptide, 65

Other words: monopoly, polygamist, polychrome, polydactyl, polycotyledon, polyester, polygene, polyglot, polygon, polygraph, polyhydric, polymorph, Polynesia, polynomial, *polyploid,* polysyllable, polytheism

-phobia-, -phobic
from L. *-phobia* fear, (hydrophobic, 64)

Other words: acrophobia (fear of heights), aerophobia (of high objects, heights), agoraphobia (of open spaces), anthrophobia (of people), arachibutyrophobia (of peanut butter sticking to roof of your mouth), botanophobia (of plants), claustrophobia (of closed places), entomophobia (of insects), hematophobia (of blood), microphobia (of small things), monophobia (of being alone), optophobia (of opening one's eyes), pathophobia (of disease), phobophobia (of one's fears), pyrophobia (of fire), sophophobia (of learning), technophobia (of technology), verbophobia (of words), xenophobia (of strangers), zoophobia (of animals)

re-
from L. *re-,* back (replication, 68)

Other presentations in text: recapitulation, 203; regeneration, 343

Other words: recognize, recycle, refer, *reflex,* rehabilitation, reinstate, remind, remit, renege, renew, repeat, *reproduction, research,* respiration, respire, return, review

-script, -scribe
from L. *scribere,* to write (transcription, 68)

Other words: circumscribe, describe, manuscript, postscript, prescribe, scribe, *Scripture,* subscribe, subscription, *superscript, transcribe,* transcript

-syn, syn-, sym-, syl-, sys-, sy-,
from Gk. *syn,* same, with, together (biosynthesis, 58)

Other presentations in text: asymmetrical, 340; chemosynthesis, 96; photosynthesis, 90; symbiosis, 286; synapse, 583; synergist, 525

Other words: *parasympathetic,* syllable, syllabus, symbol, *symmetry, sympathetic,* symphony, symptom, synchronize, syndrome, synonym, synopsis, *synthesize, synthetic*

trans-
from L. *trans,* across (transcription, 68)

Other presentations in text: translocation, 150; transpiration, 317; transverse, 339

Other words: transcendental, transfer, *transformation,* transfusion, transition, translated, translucent, transmission, transmit, transparent, transplant, transport

vita-, vivi-
from L. *vita, vivus,* life, alive (vitalism, 58)

Other presentations in text: ovoviviparous, 391; viviparous, 391.

Other words: revive, survive, *vitamin,* vivacious, vivid, vivisection, vitalize

Chapter 3A

ab-, abs-, a-
from L. *abs,* away (abscission, 304)

Other presentations in text: atrophy, 529

Other words: abscessed, abductor, abnormal, abrupt, abscond, absent, abscise, absolute, absolve, absorb, abstain, abstinence, abstract

aster-, astro-, astr-
from Gk. *aster,* star (aster, 79)

Other words: asterisk, asteroid, astrochemistry, astrocyte, astrogeology, astronaut, astronomy, astrophobia, astrophotography, astrophysics, astrosphere, astroturf, astrology

cell-
from L. *cella,* chamber (cell, 69)

Other presentations in text: extracellular, 110; intracellular, 110

Other words: *cellular, cellulose,* cellar, cellophane, cellulitis, celluloid

centri-
from L. *centrum,* center (centriole, 80)

Other words: center, central, centralize, centric, *centrifuge,* centripetal, centroid, *centromere,* centrosphere, *centrosome, concentric*

chloro-
from Gk. *khloros,* greenish yellow (chloroplast, 77)

Other presentations in text: chlorophyll, 92; Chlorophyta, 270

Other words: chloride, chlorinate, chlorine, chloroform, chlorosis

chrom-, chromo-, chromato-, chromat-, -chrome
from Gk. *khroma,* color (chromotography, 40)

Other presentations in text: chromoplast, 77; chromatophore, 397; chromatin, 82

Other words: chromatic, chromatoplysis, chrome, chromogen, chromophil, chromophore, chromosphere, phytochrome, polychrome

cili-
from L. *cilium,* eyelash (cilia, 81)

Other presentations in text: ciliary, 595; Ciliophora, 263

Other words: *ciliate,* supercilious

-cyte, cyto-
from Gk. *kutos,* bag, cell (cytology, 69)

Other presentations in text: amebocyte, 343; cytokinesis, 114; cytolysis, 85; cytoplasm, 72; erythrocyte, 552; leucocyte, 553; melanocyte, 512; osteocytes, 514; phagocytosis, 78; pinocytosis, 80

Other words: cytochemistry, cytochrome, cytogenetics, *cytokinin, cytologists,* cytopathy, cytophagy, cytoplast, *cytoskeletons*

flagell-
from L. *flagellum,* small whip (flagellum, 81)

Other presentations in text: dinoflagellate, 274

Other words: flagellate, flagellation

leuco-, leuk-
from Gk. *leukos,* clear, white (leucoplast, 77)

Other presentations in text: leucocyte, 553

Other words: leucite, leucocytosis, *leukemia,* leukoderma, leukoma

nuc-, -nucleus
from L. *nucleus,* small nut, kernel (nucleus, 70)

Other presentations in text: macronucleus, 632; micronucleus, 632

Other words: mononuclear, nuclear, nucleic acids, nucleolus, nucleotide

phago-, -phaye, phagy-
from Gk. *phagein,* to eat (phagocytosis, 78)

Other presentations in text: antophagy, 110; bacteriophage, 239; macrophages, 569

Other words: dysphagia, *esophagus,* ichthyophagus, microphages, monophage, *phagocytic,* phagosome, sarcophagus

-plasm, plasm-
from Gk. *plassein,* to mold (protoplasm, 69) (The suffix *-plasm* now refers to the material forming cells.)

Other presentations in text: cytoplasm, 72; ectoplasm, 260; endoplasm, 260; mycoplasmas, 235; plasmolysis, 85; thromboplastin, 556

Other words: leucoplasm, metaplasm, *plasma, plasmid,* plaster, plastic, *plastid*

prot-, proto-
from Gk. *protos,* first, primal (protoplasm, 69)

Other presentations in text: prothallus, 293; Protista, 215; protonema, 291

Other words: protagonist, *protein,* protistology, *Protococcus,* protoderm, protohistory, protomorphic, *proton,* prototype, *protozoan,* protozoology

somato-, soma-, -some
from Gk. *soma,* body (kinetosome, 81)

Other presentations in text: chromosome, 34; somatic, 153; trisomy, 143

Other words: psychosomatic, schistosome, somatogenic, somatotype, somatology, *trypanosoma*

Chapter 3B

hyper-
from Gk. *huper,* over, beyond (hypertonic, 85)

Other presentations in text: hypersecretion, 600

Other words: hyperactive, hyperbole, hypercritical, *hyperglycemic,* hyperopia, hypersensitive, *hypertension, hyperventilation,* hypervitaminosis

iso-
from Gk. *isos,* equal (isotonic, 84)

Other presentations in text: isogamete, 122; isometric, 528

Other words: isolate, isomorph, isosceles triangle, isothermal, *isotope*

-stasis, -status
from Gk. *stasis,* standstill (homeostasis, 83)

Other words: bacteriostatic, heliostat, rheostat, static, station, status, statute, statuary, stature, thermostat

Chapter 4A

a-, an-
from Gk. *a, an,* without (anaerobic, 97)

Other presentations in text: Agnatha, 395; amensalism, 466; anemia, 553; Anura, 407; Apoda, 406; astigmatism, 596; asymmetrical, 340; atrophy, 592

Other words: agnostic, amnesia, amoral, *anaerobe,* anarchy, *anesthetic,* anonymous, apathy, *asexual,* atheist, atypical

aer-, aero-
from Gk. *aer,* air (aerobic, 97)

Other presentations in text: anaerobic, 97

Other words: aerial, aeroballistics, aerobiology, aerodynamics, aeroembolism, aerogram, aeronautics, aerosol, aerospace

hetero-, heter-
from Gk. *heteros,* other (heterotroph, 90)

Other presentations in text: heterocyst, 233; heterogamete, 122; heterosexuality, 646; heterozygous, 127

Other words: heterochromatic, heterchromosome, heterodox, heterogeneous, heterography, heteromorphic, heteronym, heterosis

photo-, -photo
from Gk. *phos,* light (photosynthesis, 90)

Other presentations in text: photolysis, 94; photoperiodism, 325; photoreceptor, 594; phototropism, 324

Other words: photocomposition, photocopy, photoessay, photoflood, photogenic, photograph, photometer, photomicrograph, photosensitive, photosphere, phototherapy, telephoto

-troph, -trophic, tropho-, troph-
from Gk. *trophe,* nourishment (feeder) (autotroph, 90)

Other presentations in text: atrophy, 529; heterotroph, 90

Other words: allotrophy, distrophy, entrophic, eutrophy, polytrophic, trophalixis, trophic

Chapter 4B

intra-
from L. *intra,* within (intracellular, 110)

Other presentations in text: intravenous, 582

Other words: intraarterial, intraatomic, intracoastal, intracranial, intraday, intragalactic, intramolecular, intramural, intramuscular, intranuclear, intrapersonal, intrastate, intrauterine

meta-
from Gk. *meta,* change (metabolism, 102)

Other presentations in text: metamorphosis, 378

Other words: metamorphic, metaphor, metaphysics, *metatarsals, metacarpals, metabolic, metaphase,* metagenesis, metagnathous, metaprotein, metastasize, metathorax, metachromatism

Chapter 5A

-gamet, gameto-
from Gk. *gamete,* marriage, spouse (gamete, 122)

Other presentations in text: isogamete, 122; heterogamete, 122; gametophyte, 290

Other words: allogamy, bigamy, endogamy, gametogenics, heterogamy, monogamy, nogamete, polygamy

oo-, oov-, ovi-
from L. *ovum,* egg (ovum, 121)

Other presentations in text: oogenesis, 123; oogonium, 275; ovary, 294; oviparous, 391; ovipositor, 378; ovoviviparous, 391; ovule, 331

Other words: *oviduct,* oviform, ovoid, ovulation

sperm-, -sperm, spermato-
from L. *sperma,* seed (sperm, 121)

Other presentations in text: angiosperm, 294; endosperm, 332; gymnosperm, 294; spermatogenesis, 123

Other words: *spermary,* spermatic, spermatocide, spermatogonium, spermatoid, spermatophyte, spermicide, spermophile

-spore, spor-
from L. *spora,* seed (spore, 117)

Other presentations in text: ascospore, 283; basidiospore, 284; endospore, 230; sporophyte, 291; zoospore, 275; zygospore, 275

Other words: *microspore,* sporadic, *sporozoan, uridiospore*

zygo-, -zygous, -jug
from Gk. *zugon* (L. *jugum),* yoke (join) (zygote, 121)

Other presentations in text: conjugation, 232; homozygous, 127; heterozygous, 127; zoospore, 275; Zygomycota, 282; zygospore, 275

Other words: join, *jugular,* junction, juncture, juxtaposition, zygodactyl, *zygomatic,* zygosis

Chapter 5B

-hybrid
from L. *hybrida,* offspring of different parents (monohybrid, 127)

Other presentations in text: dihybrid, 134

Other words: *hybridization*

Chapter 6A

alba-
from L. *albus,* white (albino, 154)

Other presentations in text: albumen, 433; albumins, 552

Other words: alb, albedo, albite, album

-emia, hemo-
from Gk. *haima,* blood (anemia, 154)

Other presentation in text: hemoglobin, 390; hemotoxin, 419; hypoglycemia, 604

Other words: hemocyanin, hemocyte, hemodialysis, *hemophilia,* hemolysis, *hemopoetic, hemorrhage,* hemorrhoid, hematoma, hematology, hemostasis, *leukemia,* uremia

Chapter 7A

the-, theo-, theis-
from Gk. *theo,* god (theistic, 172)

Other words: *atheistic,* monotheistic, polytheism, theocentric, theocracy, theologian, theology, theomorphism

Chapter 7B

ante-
from L. *ante,* before (antediluvian, 175)

Other words: antebellum, antecedent, antedate, antefix, antenatal, *anterior,* anteroom, *anther,* anticipate, antique

post-
from L. *post,* after (postdiluvian, 177)

Other words: *posterior,* postmeridian, postmillennial, postmortem, postnasal, postoperative, postpone, postscript

Chapter 7C

anthropo-
from Gk. *anthropos,* man (anthropology, 199)

Other words: anthropic, anthropocentric, anthropogenesis, anthropomorphic

phylo-
from Gk. *phylon,* tribe, race (phylogenetic, 192)

Other presentations in text: phylum, 212

Other words: homophylic, monophyletic, phyletic, *phylogeny*

Chapter 8A

bi-
from L. *bi-,* two (binomial, 218)

Other presentations in text: biceps, 525; biennial, 299; bilateral, 340

Other words: bicentennial, bicuspid, bicycle, bifocal, bigamy, bilayer, bilingual, binocular, bisect, bivalve

Chapter 9A

bacter-, bactero-, bacterio-
from Gk. *baktron,* rod (commonly used to refer to bacteria) (bacteria, 226)

Other presentations in text: bacteriophage, 329; cyanobacteria, 253

Other words: *Acetobacter,* bacteremia, bacteriocidal, bacteriod, bacteriogenic, bacteriology, bacteriolysis, bacteriostatic, bacteriuria

con-, com-, co-
from L. *com,* with, together (conjugation, 232)

Other presentations in text: coagulation, 556; commensalism, 644; concentric, 514; conscious, 614

Other words: coenzyme, collect, commotion, commute, concern, conduct, congress, convene, cooperate, corrupt, covalent, convert

cyan-, cyano-
from Gk. *kyanos,* greenish blue (cyanobacteria, 233)

Other presentations in text: anthocyanin, 304; cyanosis, 637

Other words: cyan, cyanamide, cyanic, cyanide, cyanine, cyanophyta

cyst-
from Gk. *kystis,* bladder, pouch (heterocyst, 233)

Other presentations in text: cyst, 261; nematocyst, 345; statocyst, 368

Other words: cystic fibrosis, cystitis, cystoid, cystoscope, encyst

myco-, myci-
from Gk. *mykes,* fungus (mycoplasma, 235)

Other presentations in text: Ascomycota, 238; Zygomycota, 282

Other words: *Basidiomycota,* mycology, mycellium, myxomycota, neomycin, streptomycin

para-
from Gk. *para,* beside (parasitic, 232)

Other presentations in text: parathyroid, 601

Other words: paragraph, paralegal, parallel, paramecium, paradox, paranoid, paraphrase, parasympathetic

patho-, path
from Gk. *pathos,* emotion, suffering (pathogenic, 226)

Other words: apathy, empathy, pathology, pathos, sympathetic, sympathy

spir-
from L. *spira,* coil (spirillum, 226)

Other presentations in text: spirochetes, 235

Other words: spiral, spine

Chapter 9C

anti-
from Gk. *anti,* opposite, against (antibody, 252)

Other presentations in text: antibiotics, 252; antagonist, 525; antihistamine, 572

Other words: antichrist, *anticlotting, anticodon,* antidiuretic, antidote, *antigen, antiseptic,* antithesis, *antitoxin,* antiviral, antonym

cephal-
from Gk. *kephale*, head, brain (electroencephalogram, 256)

Other presentation in text: cephalization, 374; Cephalochordata, 389; cephalothorax, 365; cephalization, 389

Other words: cyanocephalus, encephaloma, *hydrocephalus, encephalitis*

-gram
from Gk. *gramme,* line (electroencephalogram, 256)

Other presentations in text: electrocardiogram, 560

Other words: audiogram, cablegram, chromatogram, diagram, epigram, gramophone, logogram, monogram, parallelogram, program, seismogram, telegram

mal-
from L. *malus*, bad (malignant, 254)

Other presentations in text: malaria, 265

Other words: Malacostraca, maladapted, malady, malafide, malaise, maladjustment, malapropism, maldistribution, malevolent, malefactor, malformed, malfunction, malign, malnourished, malocclusion, malodorous, malposition, malpractice, maltreat, malversation

-toxic, toxi-, toxic-
from L. *toxicum,* poison (exotoxin, 246)

Other presentations in text: cytotoxin, 574; endotoxin, 246; hemotoxin, 419; neurotoxin, 419

Other words: *antitoxin,* autotoxin, intoxicated, *toxic,* toxicology, *toxin,* toxigenic

Chapter 10A

ecto-
from Gk. *ectos*, outside, outer, external (ectoplasm, 260)

Other presentations in text: ectothermic, 392

Other words: ectomorphy, ectoparasite, ectoderm

macro-, macr-
from Gk. *macros,* large (macronucleus, 263)

Other presentations in text: macrophage, 569

Other words: Macedonia, macrocosm, macroevolution, macrogamete, macromolecule, macron, macronutrient, macrophyte, macroscopic, macrospore

-phora, -phore
from Gk. *pherein,* to bear (Ciliophora, 263)

Other presentations in text: chromatophore, 397; conidiophore, 282; Mastigophora, 264; sporangiophore, 282; sporophore, 281

Other words: *euphoria,* metaphor, trochophore

-pod, -ped
from Gk. *pous* (L. *ped),* foot (pseudopod, 261)

Other presentations in text: Apoda, 406; Arthropod, 364; centipede, 372; Chilopoda, 372; Diplopoda, 372; millipede, 373; pedipalps, 369

Other words: *biped, cephalopod,* chiliped, *gastropod,* maxilliped, pedal, pedestrian, pedestal, podiatrist, podium, tripod, uropod

pseudo-, pseud-
from Gk. *pseudes,* false (pseudopod, 261)

Other words: pseudo-Americanism, pseudocarp, pseudocoel, pseudonym, pseudopregnancy, pseudoscience

Chapter 10B

-phyta, phyto-, -phyte
from Gk. *phyton,* plant, growth (phytoplankton, 268)

Other presentations in text: Bryophyta, 268; Chlorophyta, 270; Chrysophyta, 272; epiphyte, 292; gametophyte, 290; halophyte, 322; phytochrome, 327; Pyrrophyta, 274; Rhodophyta, 274; sporophyte, 291

Other words: *Coniferophyta, Cycadophyta, Ginkgophyta,* hydrophyte, neophyte, *Psilophyta,* spermatophyte, *Sphenophyta*

pyro-, pyr-
from Gk. *pyrohos,* fire, fiery, heat (Pyrophyta, 274)

Other words: pyrochemical, pyrogenic, pyrogrophy, pyromania, pyrolysis, pyrosis, pyrostat, pyrotechnic

zoo-, zo-
from Gk. *zoion,* animal, living being (zooplankton, 268)

Other presentations in text: zoology, 337; zoospore, 275

Other words: protozoan, zodiac, zoo, zoologist, zoomorphism, zoophage, zoophile, zoophobia, zoophyte

Chapter 11

-cide, cis-, -cision
from L. *caedere,* to kill or cut (fungicide, 278)

Other presentations in text: abscission, 304; incisor, 438; insecticide, 384

Other words: algicide, decision, genocide, germicide, herbicide, homicide, incision, incisive, infanticide, larvicide, pesticide, precise, suicide

rhizo-, rad-
from Gk. *rhiza,* root (rhizoid, 281)

Other presentations in text: radicle, 334; rhizome, 309

Other words: eradicate, radish, rhizogenic, *Rhizopus*

Chapter 12A

epi-
from Gk. *epi,* upon, over (epiphyte, 292)

Other presentations in text: epicardium, 558; epidermis, 342, 509; epididymis, 629; epiphyses, 513

Other words: *epicotyl, epiglottis,* epigram, epilogue, episode, epitaph, *epithelial,* epithet

gymno-
from Gk. *gumnos,* naked (gymnosperm, 294)

Other words: gymnasium, gymnastics, gymnocarpus, Gymnodinium

-nema, nemato-
from Gk. *nema,* thread (protonema, 291)

Other presentations in text: Nematoda, 353; nematocyst, 345

Other words: nematocide

vas-, vaso-
from L. *vas,* vessel (vascular, 289) (Today *vaso-* usually refers to blood vessel.)

Other presentations in text: gastrovascular, 344; vas deferens, 629

Other words: cardiovascular, vase, vasoconstricter, vasodilation, vasectomy, *vessel*

Chapter 12B

-cycle, cyclo-, cycl-
from Gk. *kuklos,* circle (pericycle, 308)

Other words: bicycle, cyclic, cycloid, cyclometer, cyclone, cyclorama, cyclotron, epicycle, motorcycle, *noncyclic,* recycle, tricycle, unicycle

derm-, -derm, -dermis, -derme
from Gk. *derma,* skin (endodermis, 307)

Other presentations in text: dermis, 510; endoderm, 307; epidermis, 509; mesoderm, 347

Other words: dermabrasion, dermal, dermatitis, dermatoid, dermatology, dermatophyte, dermatosis, *echinoderm, ectoderm, hypodermic*

fibro-, fibr-
from L. *fibra,* fiber (fibrovascular, 313)

Other presentations in text: fibrinogen, 556; myofibril, 524

Other words: fiberboard, fiber glass, fiberize, *fibers,* fiberscope, fibril, *fibrilation,* fibroid, *fibrous, fibrosis*

meso-, mes-
from Gk. *mesos* (L. *medius*), middle (mesophyll, 303)

Other presentations in text: medial, 339; mesenchyme, 343; mesentery, 409; mesoderm, 347; mesoglea, 345

Other words: intermediate, medieval, Mediterranean, medium, medothorax, mesocarp, mesophyte, Mesopotamia, mesosome

peri-
from Gk. *peri*, around (pericycle, 308)

Other presentations in text: pericardial, 367; pericardium, 558; periosteum, 513; peripheral, 410

Other words: *pericarditis*, pericarp, pericranium, periderm, perimeter, perinatal, period, periodontal, periphery, periscope, peristyle, *peristalsis*, peristome

stomat-
from Gk. *stomata*, mouths (stomata, 302)

Other presentations in text: prostomium, 335

Other words: *stomach*, stomatic, stomatopod, stomatology

Chapter 13A

-vorous
from L. *vorare*, to devour, eat (insectivorous, 321)

Other presentations in text: carnivorous, 390; herbivorous, 390; omnivorous, 390

Other words: devour, fungivorous, graminivorous, granivorous, piscivorous, voracious

-spire
from L. *spirare*, to breathe (transpiration, 317)

Other presentations in text: expiration, 533; inspiration, 533; spiracle, 375

Other words: aspiration, *expire*, inspire, *perspire*, *respiration*

trop-, tropo-
from Gk. *tropos*, turn (tropism, 324)

Other presentations in text: adrenocorticotropic, 602; chemotropism, 324; geotropism, 324; gonadotropin, 602; hydrotropism, 324; phototropism, 324; psychotropic, 617; thigmotropism, 324

Other words: apostrophe, catastrophe, heliotrope, isotropic, nyctitropic, rheotropic, thermatotropic, *tropic*, trophy, troposphere

Chapter 14A

dors-, dorso-, dorsi-
from L. *dorsum*, back (dorsal, 339)

Other words: dossal, dossier, *dorsoventral*

-later
from L. *latus*, side (lateral, 334)

Other presentations in text: bilateral, 340

Other words: collateral, equilateral, lateral pass, multilateral, quadrilateral, trilateral, unilateral

media-, medi-
from L. *medialis*, middle (medial, 389)

Other words: median, mediastinum, *mediated*, medieval, mediocre, medium

ventr-
from L. *ventralis*, belly (ventral, 339)

Other words: *ventricle*, ventricose, ventriloquism

Chapter 14B

-fer
from L. *ferre*, to bear, carry (Porifera, 342)

Other presentations in text: efferent, 367; seminiferous, 629

Other words: conference, *conifer*, infer, offer, prefer, transfer, vociferous

gastro-
from Gk. *gaster*, belly (gastrovascular, 344)

Other presentations in text: gastric, 367; gastrodermis, 344; gastrointestinal, 539

Other words: gastritis, *gastrocemius*, *gastropod*, Gastropoda, gastroscope

or-, os-
from L. *os*, *orare*, mouth, to speak (osculum, 342)

Other presentations in text: oral, 345

Other words: oracle, orator, orifice, ostiary, ostium

Chapter 14C

nephro-, nephr-
from Gk. *nephros*, kidney (nephridia, 375)

Other presentations in text: nephron, 570

Other words: nephritis, nephridiopores, nephridium, nephritic, nephrogenic, nephrology

platy-
from Gk. *platus*, flat, broad (Platyhelminthes, 347)

Other presentations in text: planarian, 347

Other words: place, placoid, plane, plant, plate, plateau, platitude, platypus, plaza

Chapter 15A

arthro-, arthr-
from Gk. *arthron*, joint (arthropod, 364)

Other words: arthralgia, *arthritis*, arthropathy, arthroscopy, arthrosis, arthrospore

cardi-, cor-, cord-, cardia-
from Gk. *kardia* (L. *cor*), heart (pericardium, 367)

Other presentations in text: cardiac, 523; chordate, 302; electrocardium, 560; endocardium, 558; epicardium, 558; myocardium, 558; pericardial, 558

Other words: cardioaccelerator, cardiogenic, cardiogram, cardiologist, cardiopulmonary, cardiorespiratory, cardiovascular, cordial, cordiform

thora-
from Gk. *thorax,* breastplate (cephalothorax, 365)

Other words: hemothorax, thoracotomy, *thoracic, thorax*

Chapter 15B

-morph, -morphosis
from Gk. *morphe,* form (metamorphosis, 379)

Other words: allomorph, amorphosis, *anthropomorphic,* ectomorph, isomorph, *lagomorph,* morphology

ortho-, orth-
from Gk. *orthos,* straight, correct, right (orthoptera, 387)

Other words: orthochromatic, orthodontist, orthogenesis, orthographic, orthopedics, orthotropic

-ptera, pter-
from Gk. *pteron,* wing, fan (Hymenoptera, 380)

Other presentations in text: Coleoptera, 386; Dermaptera, 381; Diptera, 386; Isoptera, 381; Lepidoptera, 382; Neuroptera, 381; Orthoptera, 387

Other words: apterous, helicopter, *pteranodon,* pteropod, pterosaur

Chapter 16A

carn-
from L. *carno,* flesh (carnivorous, 390)

Other words: carnage, carnal, carnation, carnival, *Carnivora,* incarnate, reincarnation

cereb-
from L. *cerebrum,* brain (cerebrum, 391)

Other presentations in text: cerebrospinal, 585; cerebellum, 391

Other words: *cerebral,* cerebrate

hemo-, hema-, hem-
from Gk. *haima,* blood (hemoglobin, 390) (Also see *-emia* under Ch. 6A–Book 1, p. T26; Book 2, p. T20)

Other words: hematic, hematoblast, hematocrit, hematogenesis, hematoid, hematology, hematolysis, hematosis, hemocyte, hemodialysis, hemoflagellate, hemoleukocyte, hemolysis, *hemophilia,* hemophobia, *hemorrhage,* hemorrhoid, hemostat

omni-
from L. *omnis,* all (omnivore, 390)

Other words: omnibus, omnidirectional, omnifarious, omnipotent, omnipresent, omniscient

optic-, -optic
from Gk. *optos,* visible (optic lobe, 391)

Other presentations in text: optic nerve, 594

Other words: optical, optician, optometry, orthoptic, panoptic, synoptic

Chapter 16B

os-, osteo-, oste-
from Gk. *osteon,* bone (osteichthyes, 394)

Other presentations in text: endosteum, 514; ossicle, 592; ossification, 516; osteocytes, 514; periosteum, 513

Other words: osseous, ossify, ossuary, osteal, osteitis, osteoarthritis, osteoid, osteology, osteopath, osteophyte, osteoplasty, osteporosis

Chapter 16C

amphi-
from Gk. *amphi,* on both sides (Amphibia, 404)

Other words: amphibolous, amphibranch, amphiploid, amphipod, amphitheatre

Chapter 16D

neur-, neuro-
from Gk. *neuron,* nerve (neurotoxin, 419)

Other presentations in text: interneuron, 582; neuron, 518; Neuroptera, 381

Other words: *nerve,* neural, *neuritis, neurology,* neuropsychiatry, neurosis, *Neurospora*

Chapter 18A

eco-
from Gk. *oikos,* house (ecology, 453)

Other words: economics, economy, *ecosystem, ecotype*

sub-
from L. *sub,* below, under (substrate, 458)

Other presentations in text: subcutaneous, 510

Other words: *subatomic, subclavian, subconscious,* subdue, subjugate, *submarine,* submerge, *submucosa,* subnormal, *subphyla, subproducts,* subsidize, substitution, subvert, support, *suspension,* sustain

Chapter 18B

-sphere
from L. *sphera,* ball, globe (biosphere, 468)

Other words: bathosphere, chromosphere, hemisphere, hydrosphere, lithosphere, photosphere, sphere, *spherical,* spheroid, stratosphere

Chapter 19B

cutan-, cuti-
from L. *cutis,* skin (subcutaneous, 510)

Other presentations in text: cuticle, 302; pulmocutaneous, 410

Other words: cutaneous, cutinize, cutis

Chapter 19D

myo-, my-
from Gk. *mus,* muscle (myofibril, 524)

Other presentations in text: myocardium, 558

Other words: *muscle,* myalgia, *myosin*

Chapter 20A

ad-
from L. *ad-,* to, near (acclimatization, 537) (The consonant of this prefix usually changes to the first consonant of the root when combining.)

Other presentations in text: adrenal, 603; adrenocorticotropic, 602; agglutinate, 554; appendix, 543

Other words: accept, *adduct,* adjective, advent, affect, aggressive, announce, *appendage,* appreciate, arrive, attention

Chapter 20B

-ase
scientific suffix for enzyme (lipase, 547)

Other words: amylase, lactase, maltase, pepsidase

Chapter 21A

luna-, -lunar
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Other words: lunarnaut, lunate, lunatic

pulmuno-, pneumo-
from L. *pulmo,* lung (pulmonary, 559), and Gk. *pneuma,* wind, breath (often meaning *lung*)

Other presentations in text: pulmocutaneous, 410

Other words: gastropulmonary, pneumatometer, pneumectomy, pneumobacillus, pneumococcus, pneumogastric, pneumograph, *pneumonia,* pulmonic

-renal
from L. *renes,* kidney (renal, 566)

Other presentations in text: adrenal, 603; adrenocorticotropic, 602

tri-
from L. *tri,* three (tricuspid, 559)

Other words: tricolor, tricorn, tricotyledon, tricycle, triennial, trifocal, trifoliate, *triglyceride,* trihybrid, trilingual, trinomial, trio, trioxide, *triphosphate,* triple, triplicate, *triploid,* trisaccharide, *trisomy,* tritheism, triune

Chapter 22A

crani-
from L. *cranium,* head (cranial, 587)

Other words: craniate, craniectomy, craniocerebral, craniology, craniometer, craniotomy, *cranium, epicranium,* pericranium

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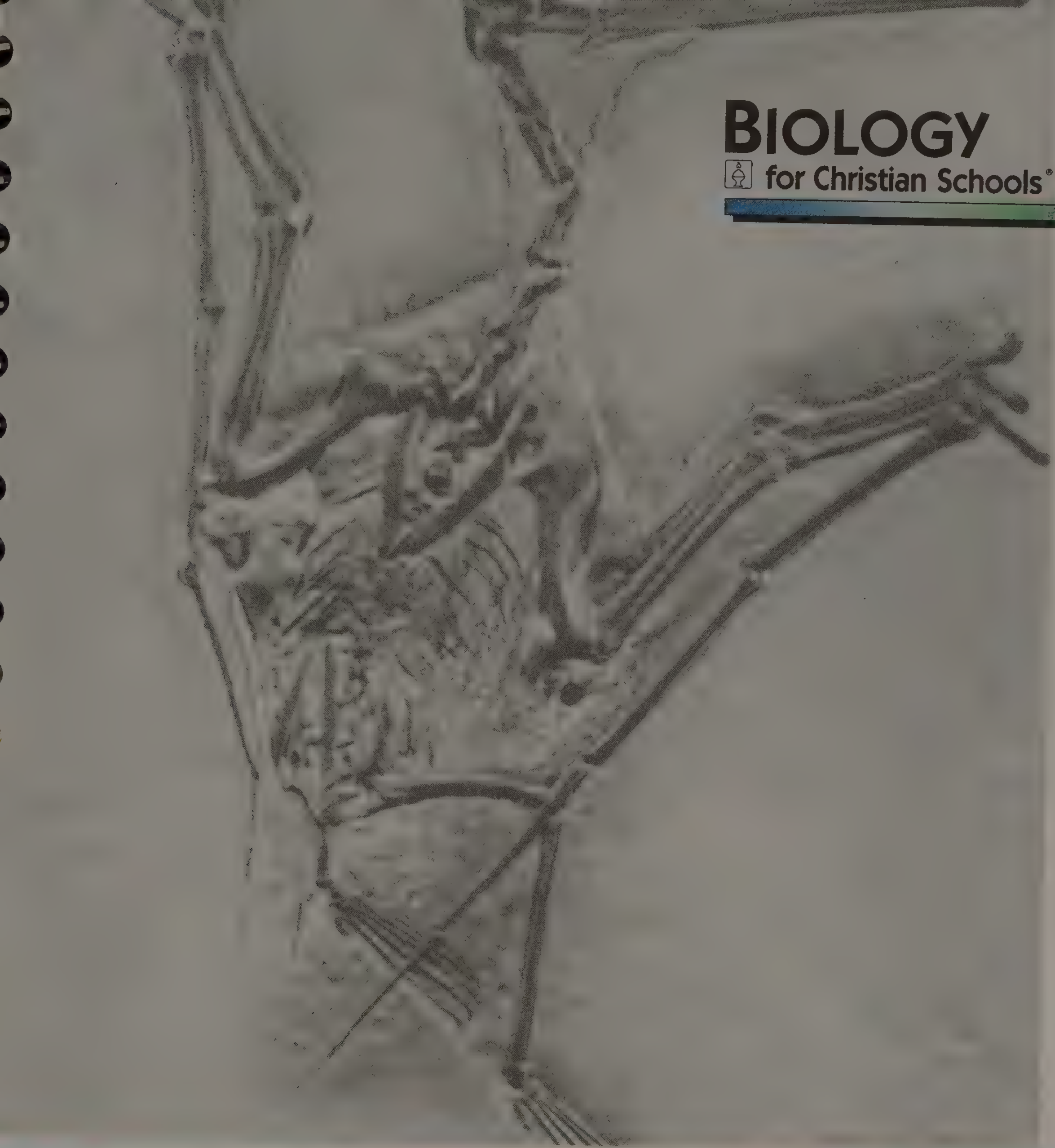

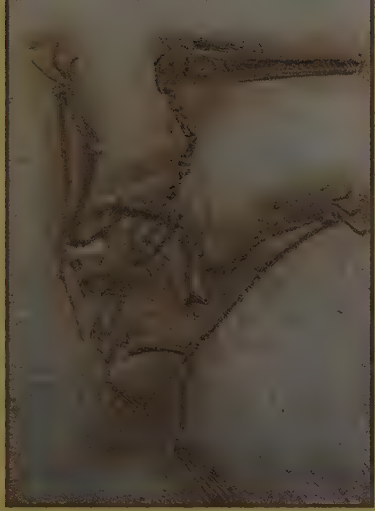

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Student Contents

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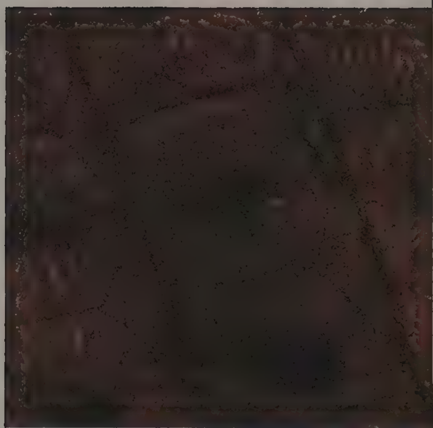


Introduction for the Student

BIOLOGY for Christian Schools® is a high school textbook for Bible-believing Christians. Those who do not believe that the Bible is the inspired, inerrant Word of God will find many points in this book puzzling. This book was not written for them.

Between true science (those things that can be accurately observed and measured) and the Bible there are no contradictions. After all, the One who wrote the Bible also created the things that scientists can observe. Men, however, can make mistakes in their observations, or they may reach a faulty conclusion from what they observe.

The people who have prepared this book have tried consistently to put the Word of God first and science second. To the best of the author's knowledge, the conclusions drawn from observable facts that are presented in this book agree with the Scriptures. If a mistake has been made (which is probable since this book was prepared by humans) and at any point God's Word is not put first, the author apologizes.

The position expressed by Dr. Bob Jones, Sr., as he said, "Whatever the Bible says is so; whatever man says may or may not be so," is the only one a Bible-believing Christian can take, but it does present some problems for a Christian high school biology student. Some of the conclusions a Christian must reach differ from those expressed by worldly sources. If your teacher assigned you to prepare a report on grasshoppers, an encyclopedia would be a logical place to begin. As you find out about the legs and wings of grasshoppers, how far these insects jump, their life cycle, how much damage they cause each year, and what type of insecticides are used to control them, you are gleaning scientific material.

The same encyclopedia article may state that the grasshopper evolved 70 million years ago. You may find a "scientific" explanation of the Biblical locust (grasshopper) plague in Egypt. You may find a description of the insects that the grasshoppers evolved from, and what insects evolved from the grasshoppers. These statements are conclusions based on "supposed science." If the conclusions contradict the Word of God, the conclusions are wrong no matter how many scientific facts may appear to back them.

The problem for the Christian biology student is not only to find information, but to consider the information in light of the Word of God. The task is not easy, but is, however, a task at which Christians need skill, not only in the sciences, but also in all areas of their lives. Keep these guidelines in mind as you start:

❑ *The Christian must know the Word of God.* This knowledge involves more than familiarity with Bible stories and some passages that are considered useful or interesting. The knowledge of the Bible needed to make good decisions comes only with years of studying the Bible and listening to good preaching and teaching. It comes only after meditating upon what God says in His Word.

❑ *The Christian must evaluate the source of the statement.* Scientific statements must be based on observation or else they are mere guesses. There is nothing wrong with a guess, as long as it is clearly labeled a guess or a belief. But Christians must disregard those guesses and beliefs that contradict the Bible.

Format of the Text

Notice the Table of Contents. This book is divided into three units. *Biology: The Science of Life* deals with topics basic to all biological studies. Much of this material concerns philosophy and

Time Frame
$\frac{1}{2}$ period

Ask students whether they agree with the philosophy presented in the first part of the Introduction. If they say yes, ask them what the philosophy is. If no, ask why not. Ask them to consider the ramifications of such a Biblical philosophy on their acceptance of science. Do the two contradict? They may have difficulty with this point. Finding the answer is the goal of the first chapter. This discussion can serve as a good diagnostic tool.

Ask what points the author feels a Christian student needs to keep in mind as he considers a source other than the Bible. Do these points agree with the stated philosophy? Do they apply to history? to spellings and meanings of words? to mathematic rules and procedures (such as long division)? These questions will present some food for thought and do not necessarily need to be answered now. Tell the students that the first chapter discusses these issues.

Make sure students grasp the basic outline format of the text.

Introduction

Objectives–Introduction

- ❑ To motivate Christian students in their study of biology
- ❑ To introduce the format of this text
- ❑ To inform students regarding the use of sections of this text

Point out to the students how the Biological Terms sections are set up. Explain class policies concerning the terms.
Give them a sample five-point reading quiz (see Book 1, p. T8). Offer them the following choices (from the Biological Terms section). Use the following:

(1) A dictionarylike section of a book
(2) A star
(3) Heavy, dark print
(4) A study of the origin of a word
(5) Have you read the Introduction thoroughly?

Choices (1-4)
(a) Asterisk
(b) Biological Terms
(c) Boldface
(d) Etymology
(e) Glossary
(f) Facet
(g) Italic

theory (guesses) and covers the area in which many of the biological discoveries that most affect our lives are made. *Biology: The Science of Organisms* is a survey of the major groups of living things on our planet. This unit takes the traditional "classificational" approach to studying organisms. *Biology: The Study of Human Life* includes human anatomy, physiology, and Christian philosophy related to our physical, mental, and spiritual selves.

Each of these units is divided into chapters. Each chapter is divided into sections, which are lettered (for example: 1A, 1B, 1C, 2A, 2B). The chapter sections are divided into subsections by large type like the "Format of the Text" above. Finally, the subsections are divided into parts by headings like "Biological Terms" below. These headings should give you insight into what you are going to read. Do not skip over them, but use them as "pause-and-gather-your-thoughts" points before going on in the text.

Biological Terms

An important part of any study is the vocabulary of the subject. Several vocabulary learning aids are incorporated into *BIOLOGY for Christian Schools*. If you use these aids, you will not only make better grades, but will also glean material useful in other areas of life. Usually the biological terms considered most important are printed in dark type, called **boldface.** Once a term has appeared in boldface, it will appear in *italic type* if it is stressed again in that chapter or in following chapters. Many biological terms of secondary importance appear in *italic type*. Italic type is also used for *emphasis* and for *scientific names*.

Every chapter section ends with a list of boldfaced terms that have appeared in the chapter. This list, called "Biological Terms," is arranged in the order the terms appear in the text. After you have read a section, you should be able to define the terms in this list. For special help and review, the **Glossary,** which begins on page 648, contains selected definitions for many terms used in this book. Unfamiliar terms used in this text often have a self-pronouncing spelling immediately following their appearance in the text.

Etymology* (ET uh MAHL uh jee) is the study of the history of words. It is useful because after you have learned a number of the common root words you should be able to figure out the meaning of some words you may not be familiar with. This text gives etymologies for certain words, each of which is marked with an **asterisk (*).** The etymology is found on the bottom of that page or the adjacent page. The first time the root is used in a chapter, it is defined. After that, only the root is given. Sometimes, if it is not obvious, the *combining form* (the prefix or suffix in current use) is given in parentheses by the root word.

This chart is for reference only.

Pronunciation Key

The pronunciations given in this text are designed to be self-evident and should give the average reader an acceptable pronunciation of the word as he reads it from the page. For accurate pronunciations, consult a good dictionary. This sample pronunciation key may help those who have difficulty with the symbols used.

Stressed syllables appear in large capital letters. Syllables with secondary stress and one-syllable words appear in small capital letters. Unstressed syllables are in lower case letters. Most consonants and combinations of consonants (ng, sh) make the sounds normally associated with them.

Some Symbol Key Words and Examples

a	cat KAT, laugh LAF	i-e	might MITE
a-e	cape KAPE, reign RANE	ih	pity PIH tee
		o	potion POH shun
ah	father FAH thur	o-e	groan GRONE
ar	car KAR	oh	own OHN
aw	all AWL, caught KAWT	oo	tune TOON
ay	neigh NAY, paint PAYNT	oy	toil TOYL
		th	thin THIN
e	jet JET		nothing NUH thing
ee	fiend FEEND	th	then THEN
eh	rebel REH bul, care KEHR	u or uh	above uh BUV
		ur	person PUR suhn
eye	ivory EYE vuh ree	wh	where WHEHR
i	women WIM un	y	mighty MY tee

Facets of Biology and boxes

A new feature in this edition is the **Facets of Biology** which you will find scattered through the book. *Facets* contain material which is related to the content of the chapter. Some of them contain interesting examples, others have additional information, and some deal with practical or Biblical applications of scientific material. Some *Facets* contain terms which are listed in the *Biological Terms* section of the chapter while others do not.

Another new feature is the **boxes.** *Boxes* are found scattered in the text and in *Facets*. Generally the *boxes* contain additional information about or examples of the scientific material being discussed in the text. Your teacher will inform you what *Facets* and *boxes* you are expected to read and which ones contain material you may be tested over.

Other study helps

Every few pages you will find a list of **Review Questions.** After carefully reading the preceding material, you should be able to answer the Review Questions. Only when you can answer these questions have you really comprehended the significant material. Some students find it profitable to read the Review Questions before they read the material. This alerts them to the most important points. When preparing for tests, you will find the Review Questions and the list of Biological Terms valuable in directing study.

The **Thought Questions** are designed to direct your attention to significant concepts that may require more knowledge than the text presented. Often you must draw from material covered in other chapters. (You may need to use the Index, pages 683-700.) Other times it will require the use of other sources such as encyclopedias, other textbooks, and, frequently, the Bible.

In the back of this book are several appendixes (pages 648-666) with which you should become familiar. Although you may not need their help every time you read this text, using these materials will often make your study of biology easier.

The *figures, tables,* and *illustrations* in this book have been designed to help you. Consider these carefully as you read the text. Some of the material in the tables and figures is reference material. You will not, of course, be expected to memorize this type of material. Your teacher will point out which tables and figures contain material you must remember and which are reference material.

At this time, check to see how well you have read this introduction by defining the following terms and answering the following questions:

Biological Terms

boldface	etymology	Review Questions
italic type	asterisk	Thought Questions
Biological Terms	Facets of Biology	
Glossary	boxes	

Review Questions

1. For what group of students was *BIOLOGY for Christian Schools* written?
2. What two points should a Christian student keep in mind as he considers any source of information other than the Bible?
3. List the topics of the three major units of this text?
4. In this text what is the significance of (a) boldface type and (b) italic type?
5. Why is the study of etymologies significant?

Thought Questions

1. Write a single paragraph to explain why you are studying biology.
2. Does Scripture have anything to say regarding the study of biology? If so, what?
3. Why would it be advantageous for a Christian young person to study biology from a Christian textbook? Would it be equally advantageous to have a "Christian encyclopedia?" Why or why not?

If you have done everything suggested in these marginal teaching notes, you have covered the Review Questions. Point out that you have done so and that if you were to test on the Introduction, they would have covered it in class. Stress the significance of knowing the answers to the Review Questions in relation to the test.

Explain class policies regarding Review and Thought Questions.

Discuss the Thought Questions as time permits.

Have students turn to the Appendixes, the Glossary, and the Index. Point out the usefulness of each and show how they are set up. Appendix B is exceptionally useful when starting Unit II. Appendix B is an outline of much of what students will be studying. Do not let them get discouraged by the appearance of this appendix. Remind them "By the yard it's hard; by the inch it's a cinch."

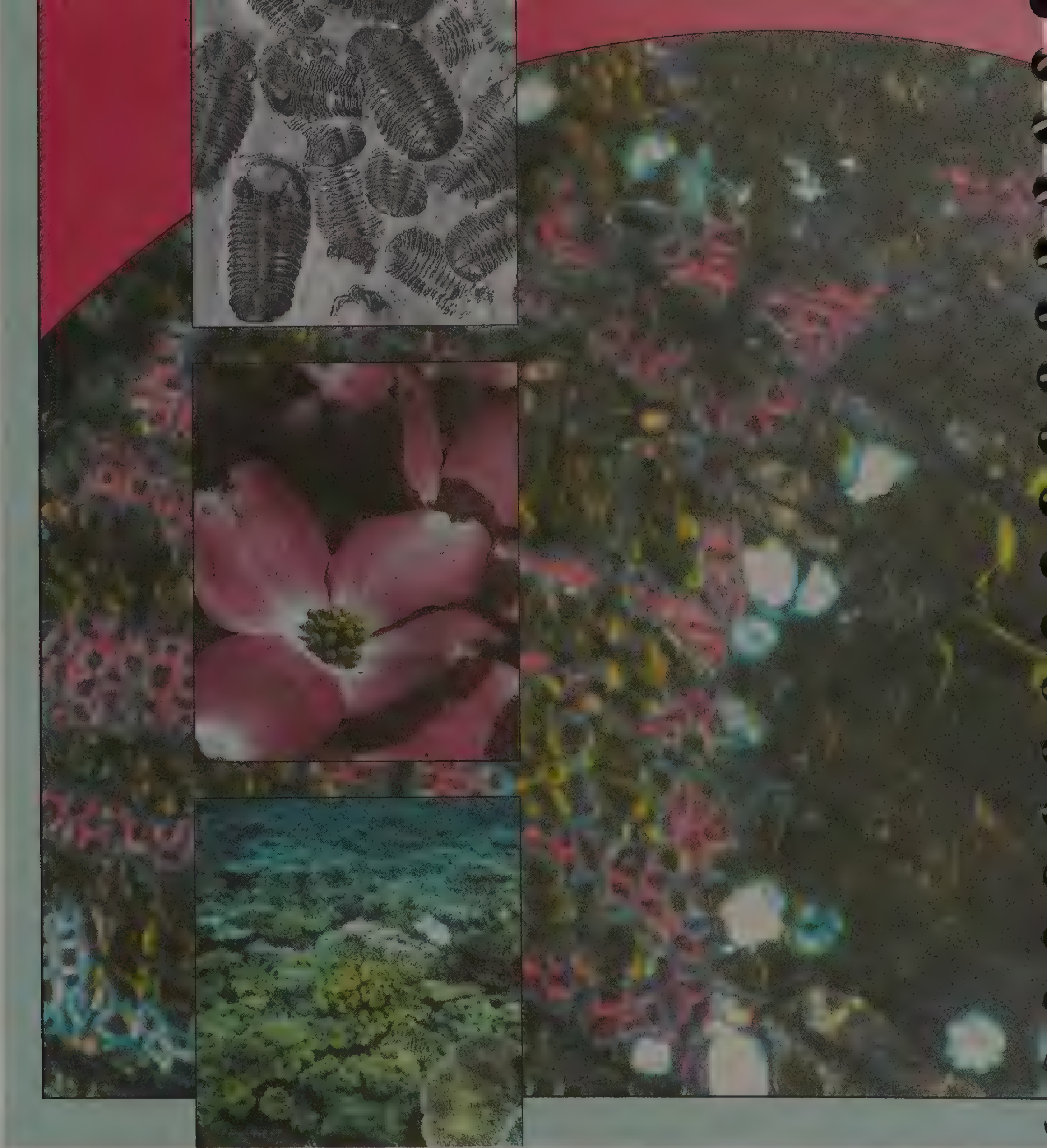
Various units of measurement are used in the text. When first presented, they are written out and/or described. If at a later time students have problems with the abbreviations of the units, they will find the last part of Appendix C (p. 667) helpful.

Answers–Review Questions

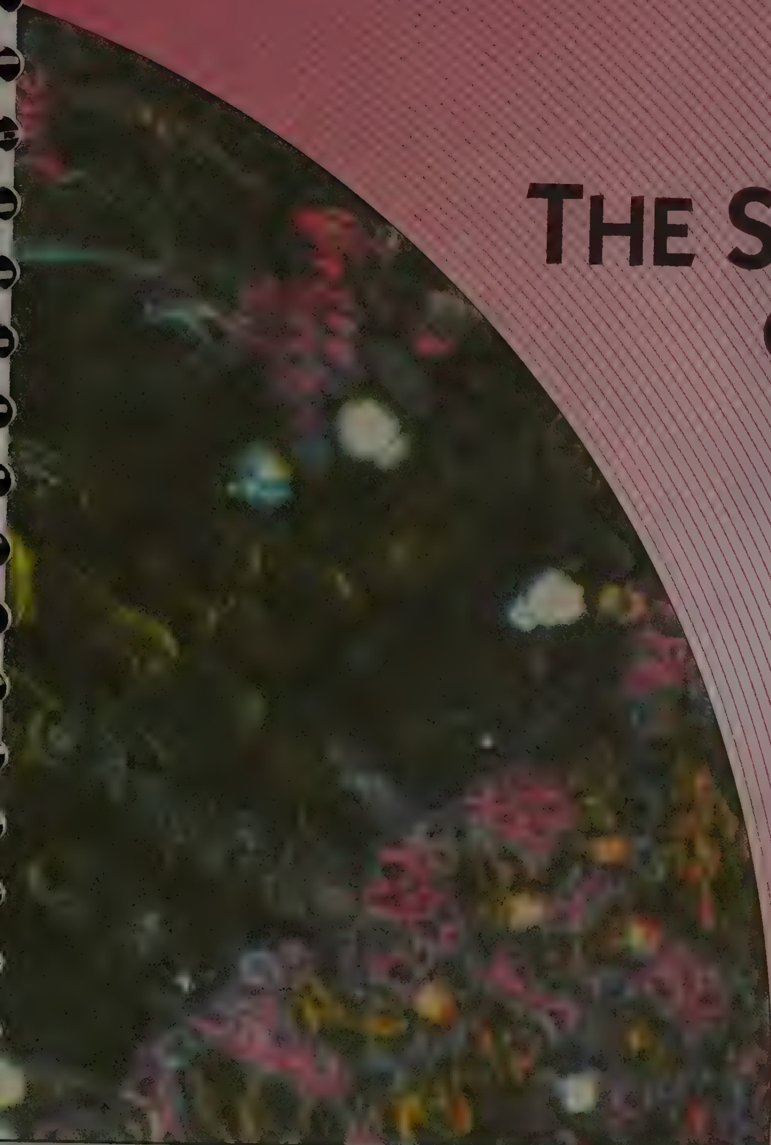
1. Bible-believing Christian high school students
2. **(1)** What the Bible has to say on the topic; **(2)** the source of the statement
3. Unit I: basics to all biological studies; Unit II: survey of living things; Unit III: human anatomy and physiology
4. **(a)** Indicates biological terms considered important; **(b)** indicates biological terms of secondary importance, emphasis, or scientific names
5. Knowing the combining forms often makes it easier to figure out the meanings of unfamiliar words.

Answers–Thought Questions

1. Answers will vary. Hopefully, the student will say, "to learn more of God through nature," but "because it's required" is most likely a bit more truthful.
2. There is no direct command to do so. However, such statements as "replenish the earth, and subdue it: and have dominion" (Gen. 1:28) and "when I consider thy heavens, the work of thy fingers . . . which thou hast ordained' (Ps. 8:3) imply a study of God's creation.
3. Answers will vary.

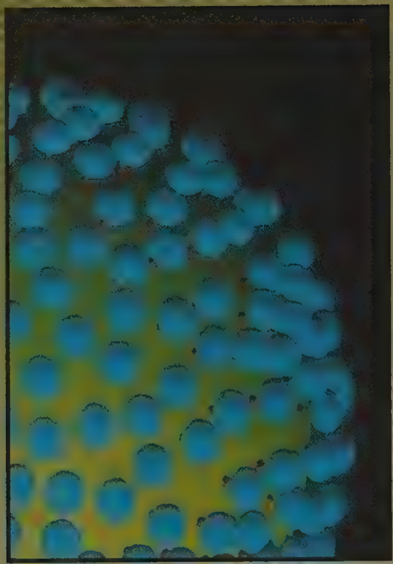


I
The Science of Life



Time Frame
1A (with Facet): 1-2 periods
1B: 1-1 $\frac{1}{2}$ periods
Facet 1B-1: $\frac{1}{2}$-1 period
1C *Attributes of Life:* 1 period
1C *The Study of Life:* 1-2 periods

Laboratory Activities
1A–*The Scientific Method* is a practical in-class example of the scientific method. 1 period, with 10-30 minutes of oral summary at another time.
1B–*The Microscope* introduces students to the care and use of the light microscope. 1 period.



ONE

THE SCIENCE OF LIFE AND THE GOD OF LIFE

1A–God and Science

Today a disease which was virtually unknown in the 1970s is a worldwide medical concern. Each year AIDS (Acquired Immune Deficiency Syndrome) kills thousands of people. Although there are good methods for preventing this disease, it is spreading rapidly.

Cancer claims thousands of lives every day. Despite claims, there seems to be little you can do to prevent many forms of cancer, and practicing one preventive measure does not mean you will not get some other form of cancer. Although there are treatments which easily cure some cancers, the treatments for other cancers are often not successful.

Most people believe that someday medical scientists will discover a prevention or a cure for AIDS and cancer. Through scientific pursuits man learned to control the Black Death which wiped out large portions of Europe's population in the 1300s. Smallpox, polio, malaria, and many other

For example, avoiding ultraviolet radiation will help prevent skin cancer, and not smoking greatly reduces the risk of lung cancer. These preventions have little or no effect on liver, stomach, or bone cancer. For additional material on AIDS and cancer, see the Index.

1–The Science of Life and the God of Life

Although students may have learned correct definitions of science in previous courses, many of them may still hold views of science that do not agree with the Bible. These misconceptions do not necessarily result from poor teaching in the classroom, but rather from the world's presentation of science as a philosophy. Chapter 1 is designed to instill the correct concept of science and its proper Scriptural position in a person's life.

Chapter 1A, *God and Science*, addresses the philosophical question "What is real?" and answers it in light of Scripture. Once it has been established that God, His Word (Truth), and what God has done (e.g., His creation) are real, reality can be studied in proper perspective.

Chapter 1B, *The Scientific Method*, examines the concept that men know truth of the physical world by observation. Science, the scientific method, and the limitations of science are examined. A study of the spontaneous generation/biogenesis controversy of the past helps to show the method and the limitations of science. The last part of Chapter 1B discusses the relationship between a Christian and modern scientific philosophy.

Chapter 1C, *Biology and the Study of Life*, begins with a definition of life, developed by describing the attributes of life. Some of the more common tools scientists use to study living things (e.g., the microscope) are then discussed. The chapter closes with a discussion of the validity of the scientific study of living things and the concept of developing scientific models.

1A–God and Science

Notes–Chapter 1A

Chapter 1A approaches the question "What is real?" in a casual, historical man-

fatal diseases have been brought under control in much of the world. Is it not logical to think that someday man will conquer AIDS and cancer?

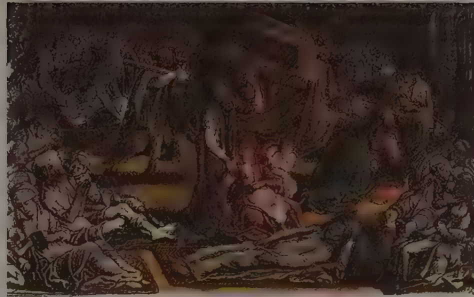
The recent population explosion has resulted in millions of hungry people on the earth. By using fertilizers and selected plants, scientists can obtain crop yields of ten times more per acre than was possible ten years ago. It seems that if the governments of the world could settle their differences, agricultural knowledge could be used to produce enough food for all mankind.

Scientists have worked out the intricate details of sending a man to the moon and bringing him back. It cannot be long before other scientists will be able to correct a malfunctioning human heart or, if the heart is beyond repair, replace it with some adequate apparatus.

Almost every day you can find something in the news about environmental pollution. Toxic wastes, harmful chemicals in drinking water, smog, oil spills, acid rain, and trash disposal that spoils the environment are real concerns. Most people assume, however, that if we just give scientists enough money they will come up with answers before the problems get too bad. Then, if we all work together and do what the scientists say we should, somehow everything will be fine.

AIDS, cancer, overpopulation, heart disorders, and pollution are but a few of the biological problems facing us today. Scientists are looking for

1A-1 *The ocean was thought to be so large that trash could be put into it and forgotten. Recently some beaches have been contaminated by washed up trash.*



1A-2 *The Black Death, a major killer of the past, is prevented by modern sanitation and medical practices.*

solutions, and since they have often been successful in the past, most people seem confident that a better life is just around the corner. But is it?

The Bible states, "Ye have the poor always with you" (Matt. 26:11). There will be sickness, suffering, and death until Christ returns for His thousand-year reign on the earth (Isa. 35:5-10; Matt. 24:5-14; Rev. 21:4). Man must now earn his bread by the sweat of his brow because of God's curse upon the earth (Gen. 3:19).

The Bible teaches that things are getting worse and that God is the source of all that is good. Some people claim that scientific efforts are improving man's existence and will continue to do so. These two statements appear to contradict each other. Which should we believe? Is one true and the other false? Are they both true? Are they both partly true? To answer these questions, one must look closely at what science is and what we know about God.

A Definition of Science

Science can be defined as a body of facts that man has gathered by observing the physical universe. (There are many other possible definitions of science, some of which will be discussed later in this chapter.) One question arises immediately from this definition of science: what are facts? A **fact** is something that is *true*. What is *truth*, and how does one know that a supposed fact is *true?* This concept has kept man's mind busy for thousands of years. Some commonly accepted theories about truth are discussed here.

Many people feel that AIDS is the unconquerable disease. Historically, however, many "unconquerable" problems have been solved. AIDS, like cancer, may be more difficult to cure than some past diseases, but that is not to say that God will not permit man to find a prevention or cure through scientific activities.

Normally, the problem is knowing enough about a subject to devise and test possible answers. The cell, although small and fragile, is yielding its secrets of structure and physiology. Only time will tell if a cure or prevention is possible for any disease or disorder. It is, however, shortsighted to classify either cancer or AIDS as unconquerable.

Actually, overpopulation is not currently (or in the immediate future) a problem regarding food. The main reason there are hungry people in the world is political (see p. 487).

ner. The text points out some ancient beliefs which, because of their novelty, will interest most students. The purpose of this material, however, is not to teach history, but rather to analyze why people held these erroneous views.

"Giggling at the old scientists" is not a goal, although they are somewhat humorous, and a few giggles are not out of place. However, students should leave the classroom knowing they must analyze the validity (truth) of a matter in the light of God's Word.

In the classroom, as the marginal notes point out, the teacher should attempt to get the students to discern modern beliefs (some that they themselves may hold) that have as little validity as these ancient beliefs.

The questions that the first few pages of the chapter might raise should be answered by *A classification of truth* (p. 12). Admittedly, this system of classification is oversimplified and somewhat artificial, but it has proved adequate for the high school student in a science course. It gives students "pigeonholes" in which to place ideas and solidly cements together a somewhat abstract philosophy.

Truth is either revealed (in Scripture) or unrevealed. Unrevealed truth is in part the realm of science which deals with physical

Objectives–Chapter 1A

- ❑ Explain the relationship between God and science.
- ❑ Define *truth*. Describe several ways to determine truth; discuss the value of these methods.
- ❑ Be able to classify statements according to the classification of truth given in the text.
- *❑ Recognize the Scripture as God's primary method of communication to man at this time.

*From a Facet.

Truth: what everybody believes?

Some facts are established according to what everybody does. The rules of grammar and spelling and the meanings of words are based on how educated people commonly write and speak. But language is manmade and man-governed. Is truth simply what everybody believes? Let us examine an idea that everybody believed to be true for hundreds of years.

Hippocrates (hih PAHK ruh TEES), a Greek physician who lived about 350 B.C., believed in the **Doctrine of Humors,** which states that living things are composed of four fluids, or ''humors.'' These humors had certain properties and were produced by specific organs. A person was healthy and happy, it was thought, when these four humors were correctly proportioned and well-mixed in the body. If, however, a person had too much or too little of one or several of these humors, his temperament (humor) was affected. For example, a person with too much blood would be warm, ruddy, friendly, and happy. If a person had too much black bile, he would be warm, sad, and melancholy.

Each individual supposedly tended toward one of these four humors. Hippocrates believed that the fluids were affected by the season, winds, temperature, sunshine, food, manner of living, age, and many other things. In winter, phlegm would dominate. If a person tended to have too much phlegm, in the winter he would be sluggish and indifferent. Severe cases of too much phlegm produced disorders such as pneumonia, dropsy, diarrhea, or dysentery. Hippocrates, who is still called ''the Father of Modern Medicine,'' believed that counteracting the predominant fluids would cure a sick person. If cold, moist phlegm entered the blood, resulting in chills, the person was to be kept warm and dry.

The Doctrine of Humors was the accepted medical practice for centuries. Today the Doctrine of Humors seems quaint or silly, yet it described

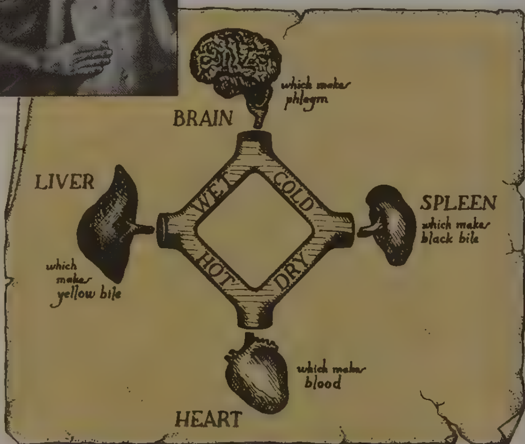
According to the Doctrine of Humors, pain occurred if there was too much or too little of one or more of the humors in an area of the body.

Visual 1A-1 can be used to discuss the Doctrine of Humors.

Teach this chart by proposing conditions and having the class play medieval physician. Example: "I have a terrible headache and get sweaty cold chills." Diagnosis: "Too much phlegm; keep yourself warm and dry. If the condition persists, I will give you some beet juice (helps to make more blood), and if the pain becomes severe, I will remove some of the phlegm by cutting open your skull and draining some of the fluid" (guaranteed to relieve headache as well as all other earthly problems).

Even today people use the phrase "out of humor," meaning they are not in a good mood. Shakespeare and other writers spoke of being in a vile or good humor.

Ask for a modern example of a generally accepted idea that may not be true (e.g., a tan is healthy). A person with bronzed skin may be deathly ill, while a pale-skinned person may be in excellent health. A deep tan can actually be harmful (see pp. 511-12).



1A-3 *Hippocrates* (left) *lived in Greece about 350 B.C. and is credited with devising the doctrine of humors* (below left). *Shown are the four organs which produce the humors and the characteristics they were believed to have caused. Hippocrates influenced medical practice for thousands of years. The Physician from Chaucer's* Canterbury Tales (right) *is described as one who "knew the cause of every malady/Were it of hot or cold, of moist or dry,/And where engendered, and of what humor"; Chaucer lived over 1700 years after Hippocrates. Even today physicians take the Hippocratic oath which Hippocrates wrote.*

phenomena. There is also unrevealed spiritual truth (how many angels fell with Satan, when certain prophecy will be fulfilled, and mysteries of Scripture like the Trinity, incarnation, and the virgin birth). The Bible tells men all they need to know to live a life pleasing to God, but it does not reveal all spiritual things. (This is developed more in Chapter 1B.)

Facet–Chapter 1A

The Facet *How God Communicates to Man* is supplemental. It should be quite simple for most Christian young people because it deals with familiar concepts. This should be a codification of belief and is designed to help them see the relationship between God and science more clearly as it is developed in the next section.

1A-4 *In 1799, George Washington's medical doctors believed that his fever was caused by too much blood. They prescribed bleeding several pints of blood. Because they believed in the Doctrine of Humors, the first President of the United States was bled to death.*

Washington's fever was probably caused by infected teeth, and some believe he would have recovered if the teeth had been cared for.

human health satisfactorily for the Greeks. Until just a few hundred years ago, almost everyone who was educated believed it. But is it *true?*

Truth: a hunch that works?

In a mathematics class, using the right method to compute a problem is sometimes considered more important than merely finding the right answer. If a student performs a series of mathematical steps with given numbers and produces the correct answer, he may assume that he followed the proper procedure, but in fact he may have made errors which were compensated for by other errors. He arrived at the correct answer but did so by mistake. The incorrect steps *worked*. Does this mean the incorrect steps are a valid method of discerning *truth?*

The ancient Babylonians used the **Doctrine of Signatures** to prescribe remedies for various ailments. In the fourteenth and fifteenth centuries Europeans promoted this doctrine to its height. They believed that when God cursed man with diseases, He mercifully left in the physical world signs (signatures) of cures for these diseases. Scriptural basis for this belief does not exist.

Medieval doctors prescribed a yellow, papery lichen (a small plantlike growth found on rocks) as a cure for a yellow condition of the skin called jaundice. The similar yellow appearance was believed to be God's sign that the lichen was the remedy. A small plant that looks like the lobe of a liver was used to cure liver infections. The plant still has the name liverwort (''liver plant''). In 1540, Dorstenius gave directions for a preparation of lungwort, a lichen that looks like a lung, as a cure for diseases of the respiratory system.

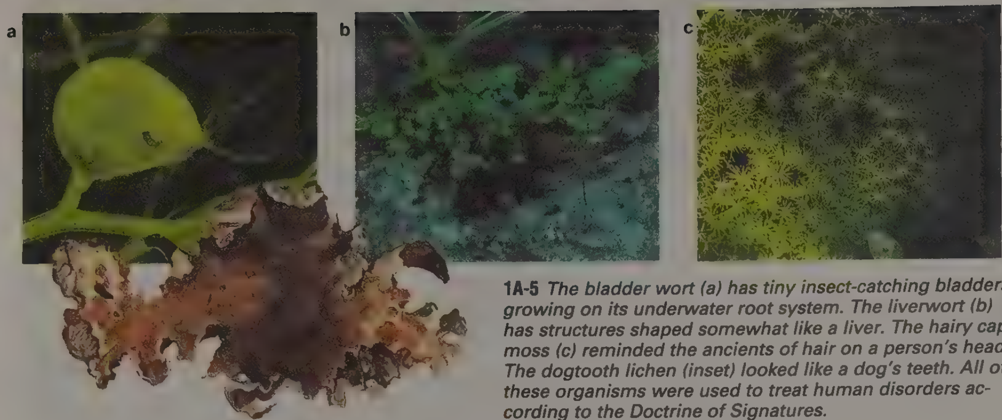
Dog's tooth lichen resembles the teeth of a dog; hence, it was thought effective against diseases related to dogs. In 1741, Dr. Richard Mead recommended it for treating rabies in humans.

> Let the patient be blooded at the arm, nine or ten ounces. Take of the herb called in Latin, *Lichen cinereus terrestris* [dog's tooth lichen] . . . clean'd, dry'd, and powder'd half an ounce. Of black pepper powder's two drachms. Mix these well together and divide the Powder into four Doses, one of which must be taken every Morning, fasting; for four Mornings successively in half

Heart-shaped leaves were often recommended to relieve heart pains. A toad's warty skin was sometimes recommended to cure warts. The medieval physician's stockroom of medicinal herbs became filled with exotic and expensive oddities dictated by the Doctrine of Signatures.

Ask students for examples of modern hunches that work (e.g., taking vitamin C to prevent a cold). After a few sneezes, a person takes large doses of vitamin C and does not develop a cold. Does the vitamin have anything to do with preventing that cold? The sneezes may have been from the excess pepper in his rabies remedy rather than a cold. The extra orange juice merely tasted good.

Quoted in John H. Bland, *Forests of Liliput: The Realm of Mosses and Lichens* (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1971), p. 111.



1A-5 *The bladder wort (a) has tiny insect-catching bladders growing on its underwater root system. The liverwort (b) has structures shaped somewhat like a liver. The hairy cap moss (c) reminded the ancients of hair on a person's head. The dogtooth lichen (inset) looked like a dog's teeth. All of these organisms were used to treat human disorders according to the Doctrine of Signatures.*

> a Pint of Cow's Milk, warm. After these four doses are taken, the Patient must go into a cold bath, or a cold Spring or River, every Morning fasting, for a Month. He must be dipt all over but not stay in (with his head above water) longer than half a minute, if the Water be very cold. After this he must go in three Times a week for a Fortnight longer.*

It is recorded that when dog's tooth lichen was served to several of the Duke of York's best dogs, they were cured of being mad.

The Doctrine of Signatures sounds absurd to the modern mind. But the medical books of the Middle Ages indicate that these remedies had cured patients (usually in "other countries" or in "olden times"). It is understandable that a medieval gentleman who had been bitten by a rabid dog would reason that if the dog's tooth lichen had cured the Duke of York's dogs and was reported to have cured a few people, it was at least worth a try. Besides, it was the only thing he could do, and to him it was probably better than doing nothing.

Scientists quickly point out that maybe these dogs and people who were reportedly cured were never really sick, or possibly their symptoms were caused by a lesser disease, a disease from which they would have recovered without the lichen-and-pepper mixture.

The finding of lichen antibiotics can be compared to getting the correct answer to a math problem on a test but using the wrong method to work the problem. The student gets credit for the correct answer, even though his knowledge and/or ability is faulty.

In the 1940s, however, it was found that some lichens do manufacture antibiotics that are effective in stopping the growth of some tuberculosis bacteria. Lichen antibiotics have been marketed commercially and have been found effective in treating wounds and burns. Is it possible that some people in the Middle Ages were actually aided by the antibiotics recently discovered in some lichens? If so, this aid could have strengthened a mistaken belief in the Doctrine of Signatures. Just because something works or appears to work, is it *true?*

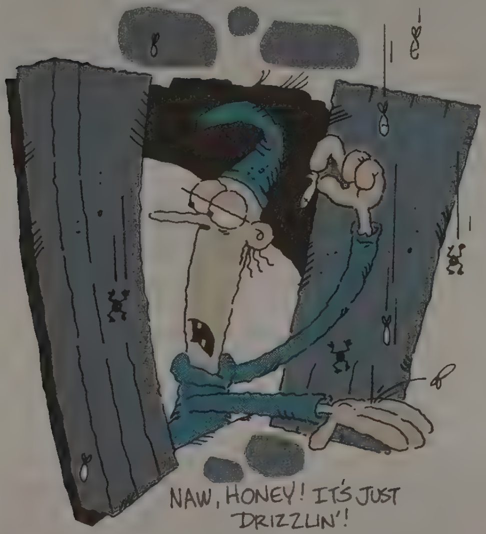
Truth: repeated observations?

Some people feel that ideas are established as true by repeated observations. If a phenomenon happens over and over again, they feel it is safe to assume that it will happen again.

If a pencil is picked up and released a few inches above a table, it will fall. This falling, which happens every time, is the effect of gravity. If you were to watch a magician seemingly suspend a person on nothing and repeat this trick several times, would this force you to alter your belief about the truth of gravity? Would observing blimps or satellites affect the truth of gravity? Are repeated observations a sure guide to truth?

The **spontaneous generation** of life from nonliving materials was believed, on the basis of observations, as early as eight hundred years before Christ. The ancients were of course familiar with

birds hatching and the birth of many animals, but some of the less familiar animals were believed to generate spontaneously whenever conditions were acceptable. In the Middle Ages, frogs and fish were thought to be formed during storms and then rained to earth. Insects supposedly came



from the soil, while maggots and worms developed from dead and decaying flesh. A fallen leaf of certain plants could develop into a fish or snake, depending on where it landed. A toad could form out of a lump of mud.

If an **infusion** * (in FYOO zhun), made by boiling animal or plant material in water, is left standing for a period of time and is then examined under a microscope, it will reveal quantities of small organisms called **microbes.*** According to most scientists from the 1700s until the mid-1800s, the microbes found in infusions spontaneously generated as the mixture began to ferment (spoil).

Some scientists held the theory that microbes came from the air; therefore, if the air were cut off, they would not develop. In 1749, John Needham, an English priest and scientist, performed a set of experiments to prove the spontaneous generation of microbes. He filled a number of glass vials with an infusion of mutton, stoppered them tightly, and heated them ''violently'' in hot ashes. He reasoned that the stoppers would prevent airborne microbes from entering the vials, and that any microbes already in the gravy would be destroyed by the heat. If there were any organisms found in his infusions, they would have had to generate spontaneously. After a few days, each of his vials was found to be teeming with microbes.

Over and over again scientists were able to demonstrate (they thought) that organisms, especially the smaller ones like microbes, would just ''happen'' if conditions were right. The fact that someone had not seen fish lay eggs that hatch into small fish but had over and over seen fish in a pond does not prove spontaneous generation. Nor did Needham's ''scientific'' experiments, however often he repeated them. He had made a mistake, an error in his reasoning, that was not obvious to him. (Needham's errors will be discussed along with other aspects of spontaneous generation later in this chapter.)

Just because you observe something repeatedly, does that make it *true?* Often the senses are fooled, or observations are made from faulty experiments.

Truth: that which is logical?

Logical reasoning constitutes truth to some people. If it makes sense, or if it can be figured out, they feel it is true. Since mathematics is logical, some would say it is true. $2 + 2 = 4$. If we define 2, +, =, and 4, we see the truth of this mathematical statement. But numbers can be made to give inaccurate descriptions of what exists. By ''juggling the figures'' a company can be made to look profitable when it is nearly bankrupt. What may appear to be logical mathematically may not be true.

Logical reasoning is usually classified as inductive or deductive. **Inductive reasoning** begins with a number of observed facts and derives from them a general conclusion. After seeing many particular objects fall and roll downhill, one perceives by induction the general principle of gravity. Scientists often repeat experiments and observations over and over to arrive at a *scientific*

infusion: in- (L. IN-, in) + -fusion (FUNDERE, to pour)

microbe: micro- (Gk. MIKROS, small) + -be, -bi, -bio, or -bios (BIOS, life)

The ancients believed that God created organisms out of the waters and the earth (Gen. 1:20, 24) and that He was still using that method to populate the earth with organisms whose reproduction they did not understand. To believe otherwise was to doubt God's Word or to limit God's power (see Facet, pp. 19-23).

Possible demonstration: Prepare infusions of bouillon cubes or boiled meat in water. Sterilize some of the infusions by boiling vigorously. Do not sterilize others. Keep all infusions tightly closed. Within a few days, the nonsterilized infusions should become cloudy with microbes.

Ask the students for modern repeated observations which may not be true. (For example, several of your friends with good-looking hair use shampoo X. The label says it is recommended by many beauticians, physicians, and mothers across America. You try it, but your hair frizzes. People's hair differs.) Other examples for discussion include such things as continental drift and certain popular medicines.

Present several simple examples of inductive and deductive reasoning. The basic problem with deductive reasoning is the necessity of absolutely accurate and exclusive statements. (All mums are short-day plants. This plant is a mum. If given short days, this plant will bloom. The mum may lack minerals or be infected, which will prevent flowering.)

Visual 1A-2, with appropriate color added, can be used as examples of deductive and inductive reasoning. Ask students what can be done to the statements in the deductive section of the visual to make them accurate for deductive reasoning. A very accurate description of an apple would be necessary (most likely requiring dozens of statements, all of which must be met) in order to deduce an apple. This will establish the difficulty of defining something. In the inductive section of the visual, ask students if something could be used to confuse this method of reasoning (e.g., plastic fruits, different-colored oranges, small oranges, odd-shaped oranges). Neither deductive nor inductive reasoning is foolproof.

Ask for a modern logical conclusion that may not be true (e.g., the recommended dose of vitamins is good, so five times that dose must be better). Sufficient understanding of the proper role of vitamins in the body would invalidate this reasoning.

1A-6 *Needham's experiment. The presence of microbes in the infusion supported Needham's belief in spontaneous generation.*

principle. But repeated observations may be faulty and cause one to arrive at an untrue principle. The fact that something can be reasoned inductively does not make it *true*.

Deductive reasoning begins with general principles assumed to be true and draws conclusions about particulars. One of the first recorded illustrations of deduction is attributed to Aristotle, describing his teacher:

Statement 1: All men are mortal.
Statement 2: Socrates is a man.
Conclusion: Socrates is mortal.

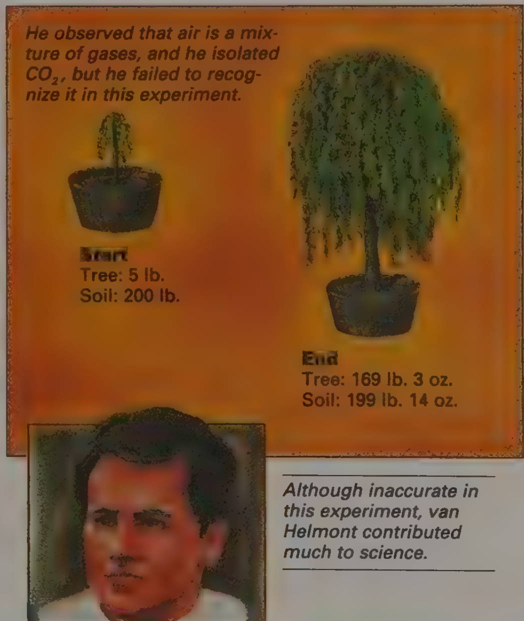
If the statements in logical reasoning are not exclusive enough, the conclusion may exhibit faulty logic and be false.

In the early 1600s, Jean Baptist van Helmont, a Belgian chemist and physician, experimented to prove that soil changed into the material that makes up plants. A large pot was filled with exactly 200 lb. of dry soil. He planted a 5-lb. willow tree in the pot and covered the pot with a shield that admitted water but excluded dust and new soil.

At the end of 5 yr. the tree was carefully removed. Its final weight was 169 lb. 3 oz., a gain of 164 lb. 3 oz. Next van Helmont dried the soil and found that only 2 oz. was missing. Obviously the entire 164 lb. 3 oz. gained by the plant had not come from the 2 oz. of soil. He concluded that the additional 164 lb. 1 oz. that the tree had grown must have come from the only other substance he knew of which the plant could get: water. Van Helmont's logic, although somewhat faulty, proceeded along these lines:

Statement 1: Plants, when growing in only soil and water, gain weight.
Statement 2: Plants gain much more weight than is taken from the soil.
Conclusion: Weight gain of plants comes almost entirely from water.

1A-7 *Jean Baptist van Helmont and his tree experiment*



Although inaccurate in this experiment, van Helmont contributed much to science.

Answers–Review Questions 1A-1

1. The four humors had to be correctly proportioned and well-mixed in the body. A person became ill if too much of one of the four humors was present in the body. For example, too much phlegm could produce pneumonia or dysentery. If the phlegm reached the blood system, it would cause fever or chills.
2. Those who believed in the Doctrine of Signatures believed that God left signs in nature that revealed the cures for various diseases. The "sign" was generally a similarity in color, shape, or overall appearance between a plant or

Van Helmont's statements are *true,* but his conclusion is false. His logical, well-designed, and carefully conducted experiment resulted in a faulty conclusion, even though the numerical information obtained was correct. Van Helmont did not take into account that plants use carbon dioxide and water to make sugar, the basic material from which plants can make other substances. The process by which plants convert water and carbon dioxide into sugar was not discovered until long after van Helmont's death. The fact that something is logical and seems to make sense does not mean it is true.

Truth: that which is accepted by faith?

What a person believes can be called his **faith.** It has been said that whatever a person believes to be true will be truth for him. A person acts because of his faith–what he believes. When you cross a bridge, you must have faith that the bridge will hold you. If you doubt the bridge's strength, you lack faith in it and probably will not cross it. However, your faith in a bridge does not mean that it is strong enough to hold you. Men may have faith in something that is not true and may act wrongly in light of their belief. If they do, they must suffer the consequences of believing something that is false.

A person going to a medical doctor has faith in that doctor. But if the doctor practices the Doctrine of Signatures, the patient may die of the cure prescribed, whether or not he believes the doctrine to be true. The patient has faith, but he believes in something that is wrong. A person may be affected by his faith or lack of faith, but does faith or lack of faith affect truth? If you do not believe there is a hell, does hell no longer exist because of your disbelief?

Truth: the Word of God

Our God is a God of truth. Christ said "I am . . . the truth" (John 14:6) and later called the Holy Spirit the "Spirit of truth" (John 14:17, 15:26, 16:13). What the God of truth says must be true. Thus Scripture, the Word of God, is truth (John 17:17). Logic, observations, workability, and common beliefs or personal faith cannot disprove these claims of the Bible.

It is true that a person must accept the truth of the Bible by faith, but that faith is not blind. The physical world around us testifies to the power of God that created and sustains it. Thus repeated, accurate observations of the world help to support the truth of the Bible (Ps. 19:1). The historical accuracy and fulfilled prophecy of the Scriptures also testify to its truth.

Our God is a God of logic. Although His ways are often beyond our understanding, "God is not the author of confusion" (I Cor. 14:33). What He does makes sense, which is the essence of logic after all.

To some people these testimonies to the truth of God's Word are not conclusive enough to justify their faith. Such people often spend time picking apart what the Bible says, looking for errors. But to those who are willing to have faith in God and His Word, these testimonies help to support their belief that God's Word is **Truth.**

Use the same process used with the apple example to determine why van Helmont's experiment did not work. He could not define plant growth because he was not able to observe it completely. Van Helmont correctly observed that air is a mixture of gases; he isolated CO_2 but failed to recognize this gas in his tree experiment (more about van Helmont, p. 19).

Although there is no record that van Helmont repeated his experiment, if he had, he would have obtained similar results.

A person's faith or lack of faith affects the situation but not the truth of something. Give examples of "sincere" but "sincerely wrong." Discuss Thought Question 3 (p. 13).

Review Questions 1A-1

1. According to the Doctrine of Humors, what conditions were necessary for a person to be happy and healthy? What could happen to a person to make him ill? What could be done to cure him?
2. On what assumption is the Doctrine of Signatures based? According to the Doctrine of Signatures, what could be done to cure an illness?
3. What evidence did those who believed in spontaneous generation offer to support their belief?
4. Give (a) an example of inductive reasoning and (b) an example of deductive reasoning.
5. Describe van Helmont's tree experiment, and tell why his conclusions were false.
6. Why is faith not a good method of determining truth?
7. List six ways man has tried to decide what is true and what is false.

other organism and the symptoms of a diseased organ or organism.

3. There were animals that the ancients had not observed reproducing. When these animals were found in places they had not been seen before, they were assumed to be there because of spontaneous generation (e.g., frogs in a summer swamp where there were no frogs in the winter). John Needham's experiments also seemed to support it. He filled glass vials with an infusion of mutton, stoppered them, and then heated them violently to kill any microbes that may have been present. A few days later, large numbers of microbes were found in the vials–supposedly a result of spontaneous generation.
4. **(a)** Inductive: The principle of gravity is induced as a result of observing falling objects and then concluding the general principle from the observed facts.

   (b) Deductive:
   1. All men are mortal.
   2. Socrates is a man.

   Conclusion: Socrates is mortal.

   (A deductive syllogism can be formed by assuming certain principles to be true and forming conclusions about specific statements associated with general principles.)
5. A 5-lb. tree was planted in 200 lb. of dry soil. For five years, only water was added. At the end of five years, the tree weighed 169 lb. 3 oz., but only 2 oz. of soil was lost. Van Helmont concluded the tree's substance must be virtually all water.
6. Men can sincerely place their faith in things which are not true.
7. Man has tried to base truth on **(1)** publicly accepted opinion, **(2)** procedures and methods that work, **(3)** repeated observations, **(4)** logic, **(5)** faith, and **(6)** the Word of God.

This Facet should be studied by most students. Omit this Facet if time is limited. This Facet presents that God's primary means of communicating to man is the Scripture, that there are other methods God uses to communicate to man (nature and the inner testimony of the Holy Spirit), and that God can use other methods, such as dreams, but if He does use other methods, their message will be harmonious with Scripture. Consider covering this Facet in a class lecture.

There are no terms in this Facet which are listed at the end of the chapter.

If there is time, this Facet can be the springboard for an excellent guided discussion regarding cults, Biblical dreams, or the inspiration of Scripture and its relationship to the revelation of God through nature (more about dreams on pp. 6, 13-14). More on the relationship between God and nature is presented later in this chapter (pp. 25, 27-29).

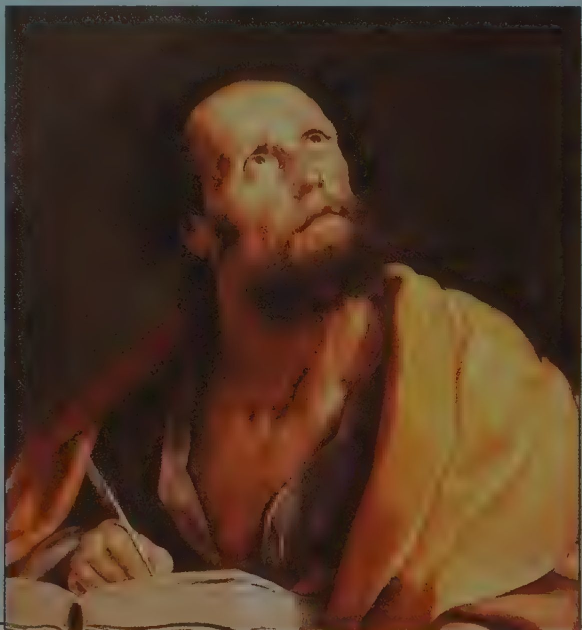
1A-1 FACETS OF BIOLOGY

How God Communicates to Man

God walked and talked with Adam in the Garden of Eden. In the Bible God spoke to some people directly and to others in dreams. Sometimes He sent angel messengers. He even wrote on tablets of stone to communicate His law to His people. But today even the best of Christians may never hear the voice of God or have a divinely sent dream or see an angel while they are in this flesh. Does God no longer speak to us? Is God now silent, leaving us to make it on our own?

Ever since the apostles finished writing the New Testament, there have been people who have claimed to have revelations from God. A well-known example happened in the 1830s. Joseph Smith, a New York farmer's son, claimed he was visited by the angel Moroni. Moroni showed him golden plates inscribed with a strange writing. Smith used special stones in silver bowls to translate these plates into Elizabethan English (the language of the King James Version).

The plates told of Christ's coming to North America and dealing with the American Indians, of how the priesthood should be reestablished, and of how God evolves into man and man evolves into God. In time, Joseph Smith and his followers were forced to leave New York and several other places because of their beliefs (which included a belief that a man may have several wives). Finally, under the leadership of Brigham Young, the group settled in Utah. Today they are called the Church of Jesus Christ of Latter-day Saints, or Mormons (after the angel Moroni).



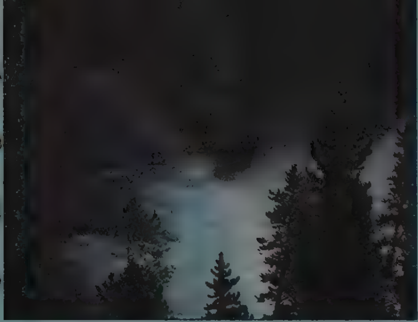
Luke by Guido Reni, Bob Jones University Collection of Sacred Art.

Was Joseph Smith's revelation from God? Based on Scripture, one must say no! The Apostle Paul tells us that if anyone (including Paul himself or even an angel) comes and preaches any other gospel, he is to be accursed (Gal. 1:8). The Bible also condemns the adding of doctrine to the Scripture (Rev. 22:18). In other words, any additional communication of God to man will not contradict the Bible, nor will it add to the Bible.

The Bible, comprising the Old and New Testaments, is the complete written Word of God to man. It contains all the spiritual truth we need to know to live in this world. The Bible, then, is God's primary communication to us. But does God only communicate to us through the reading, studying, and preaching of His Word? No. Scripture teaches us that there are two other methods God uses to communicate to all Christians.

Answers–Visual 1A-3b *(p. 12.)*

1. Have a 1-ft. ruler handy for this statement. From God's view this statement *may* be part of unrevealed truth or it may be fallacy. From man's view it is true by definition, if the ruler is accurate. The accuracy of the ruler depends upon man's ability to observe, measure, record, and analyze. Even what appears true by definition may not be true.
2. Fallacy (Gen. 1 and 2).
3. Fallacy (Gen. 8:22). Discussion of topics such as ozone-layer destruction or



❑ *Nature* is a testimony of the power of God. The very existence of our world and the universe demands belief in a Designer, Creator, and Sustainer. The more one studies the creation, the more one knows of the Creator (Ps. 19). This is one of the reasons a Christian should study science.

❑ *The inner testimony of the Holy Spirit,* given to those who in faith have found the Lord of creation, persuades the believer that God is the ultimate Truth of the universe. This testimony of the Holy Spirit can take many forms. Often it is God directing a Christian's thoughts, bringing to his mind things he should do, not do, or change in accordance with the Bible. It is the testimony of the Holy Spirit that makes the Scriptures the *living* Word of God in the Christian's heart.

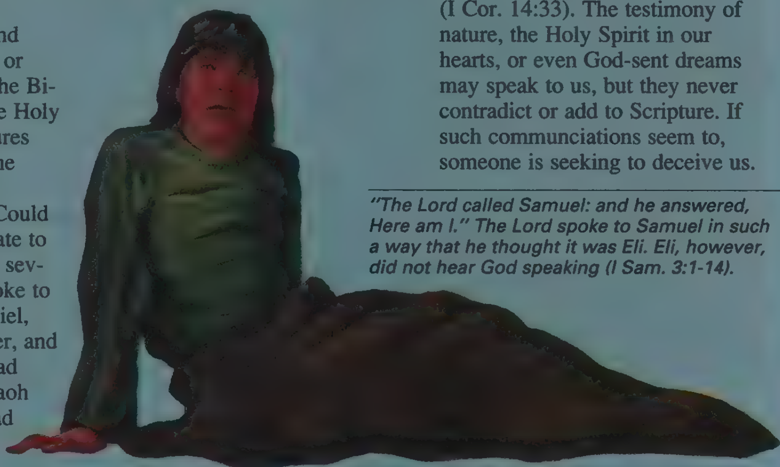
But what about dreams? Could God use them to communicate to us today? The Bible records several instances when God spoke to men in dreams. Joseph, Daniel, Samuel, Ezekiel, Jacob, Peter, and Paul are men of God who had dreams from the Lord. Pharaoh and Nebuchadnezzar also had dreams from the Lord.

Occasionally we hear of a missionary who had a dream, acted on it, and escaped great harm. We hear of other Christians who responded to dreams and were able to lead someone to Christ or received great blessing as a result. The Bible does not tell us that God will not communicate to Christians in dreams. But before we start trying to assign spiritual significance to every dream, let us consider some important aspects of sleep and dreams.

Scientists estimate that we spend about half our sleeping time dreaming. Most of our dreams last only seconds, although the actions that take place in them seem to take long periods of time. We actually remember only what we are dreaming as we wake up. It is safe to assume that God does not speak to us in every dream, for if He did, most of what He said in dreams would be lost. Most dreams, it appears, are normal functions of our mind. Such dreams lack spiritual significance.

In the past, dreams with spiritual significance have been recognized as unusual by the dreamer. When God communicates with people, He is clear and consistent. God may send these dreams to people, but He does not reveal new truth to us in dreams (Heb. 1:1-2). A God-sent dream will never contradict the principles and commands of Scripture.

The Word of God is complete. It is God's message to us, and it is forever settled in heaven. "God is not the author of confusion" (I Cor. 14:33). The testimony of nature, the Holy Spirit in our hearts, or even God-sent dreams may speak to us, but they never contradict or add to Scripture. If such communciations seem to, someone is seeking to deceive us.



"The Lord called Samuel: and he answered, Here am I." The Lord spoke to Samuel in such a way that he thought it was Eli. Eli, however, did not hear God speaking (I Sam. 3:1-14).

Review questions on page 13.

nuclear winter may come up. These may greatly harm the earth, but a world-wide ice age will not be part of any destruction described in the Bible. That, with the promise of Genesis 8:22, makes this statement a fallacy.

4. Whether one sees it as revealed or unrevealed truth depends upon the interpretation of Scripture passages such as Job 40 and 41 which many believe to be descriptions of dinosaurs (see pp. 413-15). If one believes that Scripture is vague or silent regarding dinosaurs, then the statement must be a theory. There is abundant physical evidence (e.g., bones, tracks) to demonstrate that dinosaurs did exist, which makes this statement an acceptable theory.
5. This statement could be unrevealed truth; however observations tend to place it in the fallacy category.
6. This statement could be unrevealed truth. Observations place it in the acceptable theory category.
7. True by definition.
8. See #10.
9. See #10.
10. A series of statements progressing toward "truth." In times past, the first statement could have appeared to be a good theory. Then air travel and space travel changed the validity of the first statement. This series shows how science often operates: the addition of more and more qualifiers which are increasingly technical, in an attempt to define natural phenomena. If it could be totally defined, theoretically, it could become true by definition. That much definition, however, is impossible.

These paragraphs are some of the most significant of the first chapter. They are, in effect, a statement of the relationship between God and science. Although it is relatively simple sounding and easily passed over, this concept has some far-reaching ramifications which will be discussed in later chapters. Be sure students have a solid grasp of this relationship.

Visual 1A-3a is a summary of the concept of truth as presented in the text. It can be used to cover this material. Discuss each statement. Ask students for examples of each. Note that the students' examples will need to be classified both as God looks at them and as man looks at them.

Visual 1A-3b is a list of statements to classify into various categories. Ask students to categorize a statement "from God's view" and "from man's view." The various difficulties they will have will help them to see the difficulties man has always had dealing with truth.

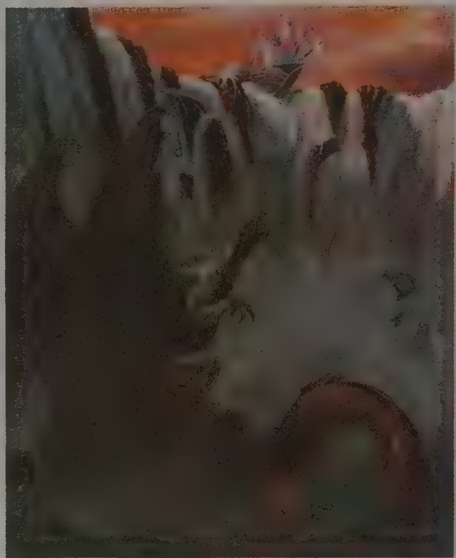
Present to them the concept that those who do not accept the Word of God as truth have only "theory" as their top level of truth. To them, all things are subject to possible reinterpretation, to change as man discovers more and makes additional observations. (This discussion can serve as an introduction to humanism and scientism which will be discussed in more detail later.)

See answers on p. 11.

God's Truth and Science

Some Christians have difficulty understanding the facts and claims of science in the light of the facts of God's truth revealed in Scripture. Let us try to put these facts in their correct places. God has directly revealed some truth to man in His Word, the Bible. This direct revelation is usually about spiritual matters–God Himself, the sinful nature of man, and the plan of redemption. But He speaks of the physical world in language and illustrations that man can understand and is accurate as He does so. After all, the same One who created the physical world inspired the Bible.

The Bible is a spiritual handbook, not a scientific textbook. It does not reveal all possible knowledge about creation. Man needs God to tell him about spiritual things which he cannot examine and experiment with. But God gives men senses and minds to observe and work with the physical truths of nature. This, then, is the **realm of science:** man's observations of the physical world. That water runs downhill is easy to observe and does not need to be dealt with in the Bible. The fact that the energy in the falling water can be used to turn the grindstones of a mill and make flour or to turn the turbines of an electric generator and supply the energy necessary to bake bread was left for man to figure



1A-8 *The flat-earth theory was once thought to be a Scriptural "fact." Careful examination of Scripture and scientific observations have shown it to be a fallacy.*

A classification of truth

Understanding God's relationship to truth may be easier if truth is classified first as God views it and then as man looks at it. From God's viewpoint a statement must be in one of three categories:

- **Revealed truth:** those truths which God recorded in Scripture;
- **Unrevealed truth:** those truths, the natural laws, that God established but did not reveal in Scripture; or
- **Fallacy:** any statement not part of revealed or unrevealed truth.

When man looks at a statement, whether based on repeated observations, a hunch, logic, or even faith, it must fit under one of four categories:

- **Revealed truth:** that which is revealed in Scripture, whether or not man has scientifically proved it. If it is in the Bible, it is already true, without other proof.
- **Theory:** that which is thought to be true, is not revealed truth, but may be part of unrevealed truth.
- **Fallacy:** that which is contradicted by God's revealed truth, no matter how scientific, how commonly believed, or how apparently workable it may seem; or that which is contradicted by scientific evidence.
- **Truth by definition:** that which is true because man has defined it, as in mathematics, grammar, spelling, and meanings of words. For example, because man can define numbers, he can arrive at mathematical conclusions which are based on logic and by definition are true. To the extent that man correctly uses his tools (be they rulers or calculators), such fields as measurements and geometry can be considered true by definition.

No amount of work on the part of man can make a theory part of God's revealed truth. But

Answers–Review Questions 1A-2

1. Revealed truth is what God has recorded in Scripture; unrevealed truth includes the spiritual and physical truths and natural laws not revealed in Scripture.
2. God's truth is revealed in His Word and is true whether or not men have proved it. Theories are unproved ideas, not revealed in Scripture; they may be true as a part of God's unrevealed truth, but all are not necessarily true. Only that which is already in the Word of God is revealed truth.
3. **(1)** God's Word contradicts it. **(2)** Scientific evidence contradicts it.
4. The meanings of words and rules of mathematics, grammar, and spelling are true by man's definition. Examples: **(1)** When any number is multiplied by 1, the product is equal to that same number ($12 \times 1 = 12$ is a mathematical definition). **(2)** An adverb is used in a sentence to modify verbs, adjectives, or other adverbs in that sentence. It never modifies a noun or subject within the sentence (English grammar definition). **(3)** *Q* is followed by *u* in English words (spelling definition).

Answers–Facet 1A-1

1. Bible, nature, inner testimony of the Holy Spirit

some theories, such as the Doctrine of Signatures or the Flat Earth Theory, were once thought to be supported by Scripture since they were "hinted at," it seemed, in the Bible. The Scriptures used, however, were taken out of context. A Christian must be very careful not to take verses out of context or to take a passage he does not understand and try to make it say what he wants. Because all truth is not revealed in the Bible, a Christian should not try to make the Bible deal with all topics.

Science, then, is man's attempts to observe and describe the natural processes God established to govern the universe.

For a Christian who claims Biblical salvation, the only logical tenet is that God's Word is true. If there is an error in the truth of the Word of God–if the Bible is subject to the possibility of error–salvation and even the very existence of God become questionable. Christians should accept the whole Word of God by faith and not pick and choose. Who is capable of picking and choosing the truth? by what method?

Biological Terms

A Definition of Science	spontaneous generation	deductive reasoning	revealed truth
science	infusion	faith	unrevealed truth
fact	microbe	truth	theory
Doctrine of Humors	logical reasoning	*God's Truth and Science*	fallacy
Doctrine of Signatures	inductive reasoning	realm of science	truth by definition

Review Questions 1A-2

1. What is revealed truth? What is unrevealed truth?
2. What is the difference between revealed truth and man's theories? Can a theory become part of revealed truth if enough supporting evidence is obtained? Why or why not?
3. List two ways a theory can be shown to be a fallacy.
4. What types of statements can be true by definition? List several statements that can be considered true by definition.

Facet 1A-1: How God Communicates to Man, pages 10-11

1. List the three major ways that God communicates to all Christians.
2. If someone claims that something is a teaching of God, how can you know if what the person says is truly from God?
3. Some people say that God does not communicate to humans by dreams in this present age. Is this true? Why?

Thought Questions

1. Classify the following statements as either (a) part of revealed truth, (b) possibly part of unrevealed truth, or (c) fallacy.
   (1) Man evolved from apes.
   (2) What goes up must come down.
   (3) An Ice Age in which all the earth will experience extreme cold is coming.
   (4) Water runs downhill.
   (5) Sentences end with periods, exclamation points, or question marks.
   (6) If a man is hot and flushed, he should be treated by bleeding.
   (7) The earth will never be completely flooded by water.
   (8) All things that are physically alive must die.
2. Classify the statements given in number one above as either (a) revealed truth, (b) a theory, (c) a fallacy, or (d) true by definition.
3. It has been said, "Only what I believe can be true for me." Can something be true if a person does not have faith to believe it? Give examples to prove your position.
4. Give two examples of modern beliefs which are not true.
5. "The Bible does not deal with modern science; therefore, science is of the devil." Give reasons to contradict or support this statement.
6. Physical phenomena (plants, mountains, gravity, animals, life, etc.) cannot be completely defined. Manmade phenomena (numbers, spelling, grammar, etc.) can be defined completely. Explain how the ability to be defined limits man's ability to know truth.

Stress these three significant statements: **(1)** Man cannot make what is not in the Bible as true as what is in the Bible. **(2)** Do not take a Bible passage out of context to try to prove things. **(3)** Since God did not reveal all truth in the Bible, do not try to make the Bible explain the details of all physical things.
Many students with good Christian backgrounds have heard these principles many times but are still prone to scientific and Biblical errors that arise from not following them.

The last paragraph is a workable, though possibly incomplete, definition of science that fits well within the framework of Scripture (see more complete definitions of science on p. 25). Most scientists without a Scriptural orientation would object to it.

Use Thought Questions 1 and 2 (p. 13) as a homework assignment. Tell students that their ideas will be discussed in class the next day. The questions can also be used for group discussion.

2. Check the Bible to see if what the person says agrees with what God has already said.
3. The Bible does not say that God will not use dreams to communicate to men in this present age, but the Scriptures do state that no new doctrine will be revealed by any means.

Answers–Thought Questions

1. **(1)** C; **(2)** B; **(3)** C; **(4)** B; **(5)** B; **(6)** C; **(7)** A; **(8)** A
2. **(1)** C (Gen. 1 and 2); **(2)** C (spacecraft); **(3)** C (Gen. 8:22); **(4)** B; **(5)** D; **(6)** C; **(7)** A (Gen. 9:11-12); **(8)** A (Heb. 9:27)
3. Yes. Creation by God, salvation through Jesus Christ, and condemnation of sinners to an eternal hell are true even though some people have not accepted these facts.
4. **(1)** Theory of evolution. **(2)** Science will eventually find cures for all diseases and will ultimately answer all questions about the origin of the universe.
5. It is not true. Science is a study of God's creation and therefore supports and strengthens faith in the Bible. True science refutes evolution by supporting creation, and it therefore reveals the Devil as a deceiver.
6. If a phenomenon cannot be clearly defined, it cannot be clearly understood. For example, everyone experiences the effects of gravity and light, but man is unable to completely define the nature of these phenomena. Man cannot, therefore, know exactly what is true about them.

hypothesis: hypo- (Gk. HUPO, beneath or under) + -thesis (TITHENAI, to place)

The "magical aura" placed around scientists at work is, in good part, an attempt to replace trust in God with trust in science. Be careful, however, not to make science look so negative that it seems to have no merit. The scientific method of reasoning is the only method man has of learning about the physical universe in matters Scripture does not specifically mention. Recognize the limitations of science, but do not stress them so much that the students see science as useless or anti-God.

Now is the time to begin presenting the idea of science fair projects if they are a course requirement.

A survey is a scientific activity (not an opinion poll) that is often overlooked. Data are obtained by observation and can be subjected to classification. How to conduct a good survey is a study in itself. Not having random samples, typical samples, or adequate samples is a problem that can hurt the validity of the data. Consider having the class conduct a survey in the school (possibly during a lunch hour) regarding something like fruit for breakfast, mothers who work, or car color. Then ask the class what could be wrong with their survey techniques that would result in poor validity. Apply this to the "polls" taken for elections or other surveys.

1B–The Scientific Method

For some people the thought of a scientist using the scientific method produces visions of a man in a white coat, with a clipboard, looking at dials and flashing lights on a large console, surrounded by a complex system of glass tubes and flasks, doing things difficult to be understood even when he tries to explain them in simple language. Most people who have these mental pictures have great respect, even awe, for scientists who can use the scientific method.

Scientists may sometimes wear white coats, use elaborate equipment, and perform experiments that are difficult to explain, but none of these makes a scientist different from other skilled persons. The **scientific method** is not a "magical," miracle-working formula which will solve all man's problems. It is, rather, a method of reasoning that you use daily.

The scientific method is simply a logical procedure for choosing an answer to a question. For example, after examining hundreds of ripe oranges, a person could use deductive reasoning to say, "Ripe oranges are orange in color and nearly round." Such deductive reasoning is characteristic of what scientists often do, and of what you do to employ the scientific method.

Using the Scientific Method

Although there is no set order of activities, you will usually do all the following preliminary steps at one point or another when using the scientific method of collecting information.

❑ *Define the problem.* Before the actual experiment begins, you will state the specific question or problem to be solved. It must be limited sufficiently so that it can be dealt with conveniently. The question "What makes plants grow?" is too broad and indefinite; but "Do geraniums grow better in dim or bright light?" is limited enough to be answered by experimentation.

❑ *Do preliminary research.* Once the problem has been stated, you should **research** to become familiar with the relevant area of science. Perhaps your problem has already been solved by someone else; if so, experimentation would be unnecessary. In any case, research in books and magazines and conversations with knowledgeable people will help you understand your problem better and avoid foolish mistakes.

❑ *Form the hypothesis.* Once you have stated the question and researched it completely, you will usually formulate a **hypothesis** * (hye PAH thuh sis)–an educated guess which attempts to answer the problem. You will then devise activities to see whether that hypothesis is correct.

Steps of the scientific method

The activities used to test a hypothesis can be an experiment or a survey. If an **experiment** is to be used, you must tailor it to answer the problem precisely. When the problem asks what exists in a particular area or what is common practice, a **survey** is necessary. For example, which pain

1B–The Scientific Method

Notes–Chapter 1B

The beginning of Chapter 1B presents the scientific method, stressing the limitations and the scope of science. Many high school students can easily memorize the proper definitions and list of phrases they need to "demonstrate an understanding," as it is put in present educational jargon. However, every year thousands of science fair projects reveal that students have not the foggiest idea of what they are talking about. Some of the teaching suggestions in the text are designed to help the teacher help the students "experience" the scientific method.

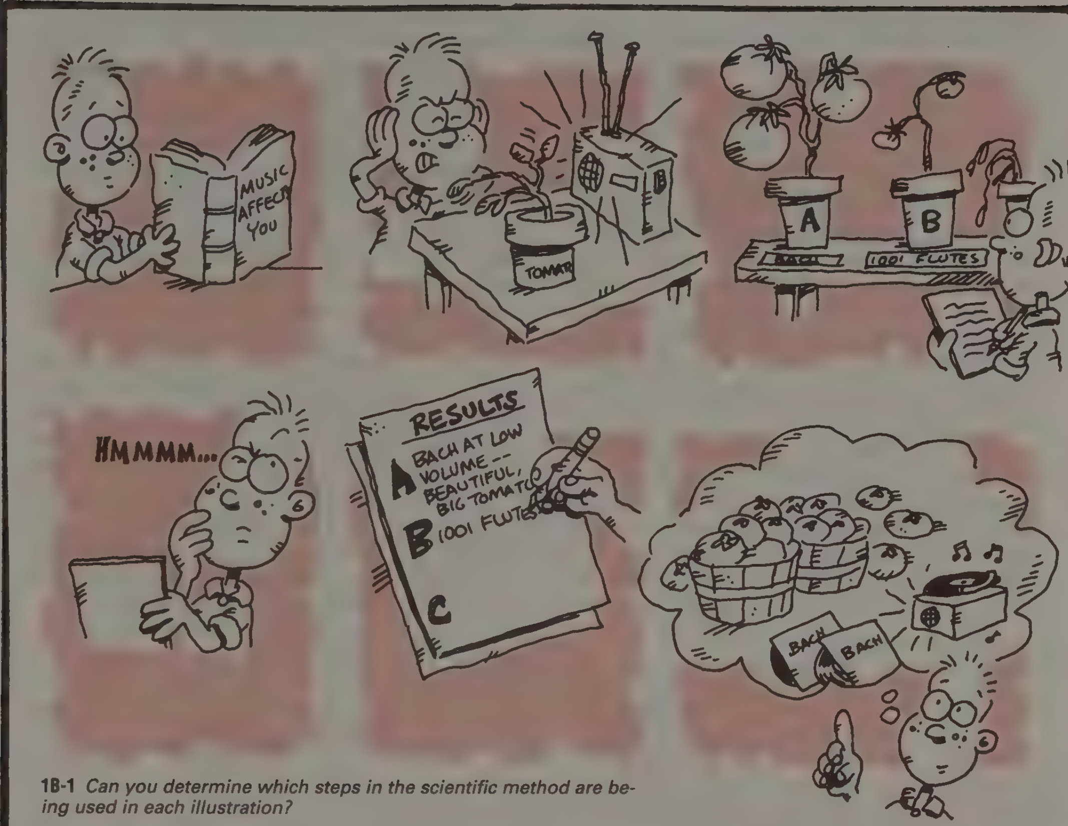
Teachers with advanced classes or with a special interest in the area may wish to cover *A History of Scientific Thinking* (Appendix A, pp. 648-51) in conjunction with this chapter.

Too frequently, Christian science courses stop at showing the limitations and fallacies of poor science. Science, however, is a tool, ordained by God for man's use. Teachers must be careful that science does not appear to the student to be only a "tool of Satan." Students should not be left wondering why they should study biology in a Christian school.

Objectives–Chapter 1B

❑ List, describe, and know the significance of the steps of the scientific method.
❑ Recognize the limitations of science.
❑ Describe a Scriptural philosophy of science, explaining the relationship between science and Scripture.
*❑ List and explain several historical proofs for biogenesis.

*From a Facet.



1B-1 *Can you determine which steps in the scientific method are being used in each illustration?*

remedy doctors recommend most or what kind of tree is most common in a certain area would be answered by surveys, not experiments.

Once the experiment or survey has been constructed, you will go through the following steps:

❑ *Observe* the experiment or survey carefully.

❑ *Collect* information from the experiment or survey and record it accurately. The recorded information is the **data** you will use to solve the problem.

❑ *Classify* the data into a logical order or into logical groups.

❑ *Analyze* the data to determine what it reveals about the problem.

❑ *Choose* from among the several answers suggested by the data the one that best answers the question. (In some cases the data may suggest only one answer.) If the data point to an answer different from the original hypothesis, then the original hypothesis should be discarded.

❑ *Verify* the chosen answer by repeating the experiment. The more often a well-designed experiment is repeated and produces similar results, the more valid and reliable is the answer.

❑ *Predict* what will happen in similar situations. The goal of using the scientific method is to be able to draw conclusions that can be applied to similar cases.

Science and the Christian, the last part of Chapter 1B, deals with man's use of science and a Christian's attitude toward science. Although difficult to teach and hard to keep in balance (since science is easily misused), this point is essential if Christian students are to have the proper attitude toward science. This section should not be omitted by any Christian school. It is basic philosophical material. Carefully present this material "line upon line, precept upon precept."

Facet–Chapter 1B

The Facet *Spontaneous Generation and the Scientific Method* is a historical look at the use of the scientific method. After a thorough discussion of the scientific method, the students should be able to determine what points of the scientific method were either overlooked or misused in the historical examples. This may be another place to "giggle at the old gents," but it should also be a learning experience. Pointing out past science fair experiments or even actual research by scientists that have had similar problems should help the students take the philosophical points from the old and apply them to the modern real-life situations. Covering this Facet will make the opening section of Chapter 1B more meaningful. Be careful not to stress the memorization of dates and people to the exclusion of the contribution they made to the controversy.

variable: (L. VARIUS, changeable)

phenomena: (Gk. PHAINEIN, to show)

Controlled experiments

An ideal scientific experiment is sometimes called a **controlled experiment.** In a controlled experiment there are two identical groups, and the difference between the two groups is a single factor called the **experimental variable.***

The group not exposed to the experimental variable is the **control group,** and the group exposed to the experimental variable is the **experimental group.** As an example, consider two sets of mice grown in identical cages in the same room with the same diets. If one group has a vitamin dissolved in its water, it would be the experimental group, and the vitamin would be the experimental variable; the other group of mice would be the control group.

Normally, *multiple variables* in a controlled experiment are unacceptable. If an experiment has more than one variable, you would not know which variable was responsible for the observed results. If the experimental group of mice was given larger cages than the control group, the results obtained might be caused by the added space (or both the added space and the vitamins) rather than just the vitamins.

Fewer variables give more *valid* (accurate and reliable) results. That is, if you repeated the experiment, you would get the same (or very similar) results. If you do not get the same or very similar results each time, your results are not considered valid. To insure valid results, scientists often repeat experiments. If the results are the same a significant number of times, the insignificant results are blamed on some uncontrolled variable in the experiment, and those results are often ignored.

If in the mice-and-vitamin experiment 99 of the 100 mice in the experimental group grew longer fur than the mice in the control group, you have data, but it may not be valid. If you repeated this experiment fifty times and each time 95 to 100 of the experimental group had longer fur and only 1 to 5 of the control group had longer fur, your results have a good level of validity. The more you repeat your experiment with similar results, the more valid are your results.

Review Questions 1B-1

1. List and describe the activities involved in the scientific method.
2. What types of cases are best investigated with a survey rather than an experiment?
3. A problem that is investigated by the scientific method must have what two limitations? Why is each of these limitations necessary?
4. Why must an experiment or a survey be controlled? What is the difference between the control group and the experimental group in a controlled experiment?

The Limits of Science

The very nature of the scientific method greatly limits science. Although some people attribute godlike capabilities to science, science is actually little more than what man can sense around him. No matter how often an experiment or survey is repeated, no matter how carefully observed, no matter how accurately recorded, no matter how well it works and how valid it appears, a scientific "fact" can, and often has been wrong. To understand why, you must recognize the limitations of science.

Limitations inherent in the scientific method

Scientific investigations must deal with physical phenomena* (fih NAHM uh nuh), because experiments or surveys must have *observable, measurable* data to support a conclusion. A problem investigated by the scientific method is generally stated so that it can be answered with a yes, a no, or a number (such as a percent or ratio). Questions

Review Questions 1B-1

1. **(a)** Preliminary steps: **(1)** Define the problem or question to be solved. The statement should be narrowed down or limited–not generalized–so that the problem can be dealt with specifically through a survey or an experiment. **(2)** Do research to become familiar with as much information as possible for the planned experiment/survey. The researcher will then better understand the problem at hand and avoid unnecessary mistakes. **(3)** State a hypothesis–an "educated guess"–that will serve to guide the researcher in his experimentation and research. **(4)** An experiment or survey is then performed to obtain data to support (or disprove) the hypothesis. **(b)** Steps of the scientific method: **(1)** Observe the experiment or survey carefully. **(2)** Collect data (information resulting from observation) and record accurately. **(3)** Classify or organize the data into logical order or groupings. **(4)** Analyze the data to determine what they reveal or suggest about the problem. **(5)** Choose the best possible solution to the problem. Choose objectively in light of the observations and data collected; if the original hypothesis is not supported by the data, discard it and propose a new solution that best fits the results obtained. **(6)** Verify the chosen solution by repeating the survey or experiment. If the same results occur in great frequency, the experiment and data may be considered valid and reliable. **(7)** Predict what will occur in similar situations; determine how the results and conclusions can be used in other ways.
2. Problems which concern the existence of something in a particular area or which describe common practice in a certain area make good surveys.
3. **(1)** It must deal with physical phenomena. If the thing investigated cannot be observed or measured, it does not fall

Using the Scientific Method

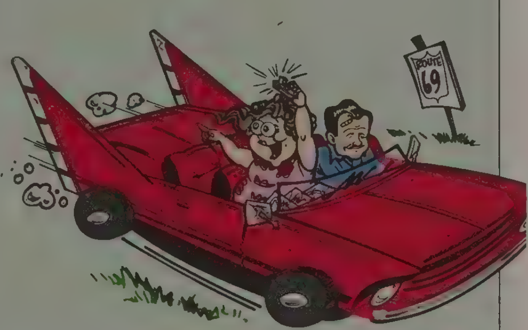
Many people use the scientific method of thinking every day. That is not to say that it is always used well. Often the limitations of the method, the controls, or the repetitions needed to obtain valid workable results are not considered.

Consider the following example: Assume that a family is planning a trip to Detroit and wonders which way is quicker: the expressway, which takes a roundabout route but promises rapid travel; or the back roads, which take a more direct route. Since time is measurable, the problem is within the scope of science. Using a map, a ruler, and a pencil, one could come up with a good hypothesis. To make sure the hypothesis is correct, however, experimentation is necessary. A member of the family could obtain data by driving to Detroit on one route, carefully recording the time and the mileage, and then taking the other route when coming home, again recording the time and mileage.

He must be careful to record exact times for every stop. Having to decide, "I guess it took us about half an hour to eat," would destroy the validity of the results. The traffic jam on the interstate in Toledo and the road work along the country road will affect the validity of the results by adding other variables. If he travels one route in the early morning and the other late at night, there would be more variables: the route and the time of day. It would be best if the experiment could be *controlled* so that there is only one variable (in this case, the route).

Controls on all the possible variables along hundreds of miles of roads would be difficult, if not impossible. To have more valid results, the experiment should be repeated many times and the results averaged. If the results of three round trips indicate that one route averages five minutes less than the other, is the conclusion valid? Since it is based on such a small number of repetitions, the five minutes difference could easily be the result of variables other than route.

But when Mother states that she likes the back roads because they are more scenic, the scientific method can no longer be applied. Science cannot deal with beauty or other value judgments, because such are not measurable physical phenomena. The number of bumps in the road and the number of restaurants on the route could be determined by surveys. The amount of gasoline necessary for each route or the wear on the tires could be determined by experimentation. These are within the scope of science. No experiments can be devised, however, to test the beauty of one route as compared to another. When it comes to which route the family *wants* to travel, science yields to the authority of man's will.



This box contains supplemental material which should be studied by most students. This box presents the limits of science. The goal is to give students everyday examples of the use of the scientific method to help demystify the concept. There are no terms in this box which are listed at the end of the chapter.

Using this example of the scientific method should cause the students to see that the scientific method of reasoning, controlled experiments, and the limitations of science do not apply only to the white-coated scientist in the laboratory. Ask students to come up with other examples of daily use of the scientific method and problems inherent in its use.

using how or why are not measurable and are therefore beyond the scope of science. The scientific method cannot *explain* a phenomenon.

Measurable, observable results require the use of most if not all of man's senses. The phenomenon must be seen, felt, heard, tasted, or smelled. Man's senses, of course, are often not accurate and can be fooled. If the phenomenon cannot be observed, a device capable of measuring the phenomenon must be used. Man cannot sense X-rays, for example, but photographic plates and other devices can measure the presence of X-rays. Using more devices to make observations introduces more variables which then increase the possibility of mechanical errors.

The beginning of life, what is in the future, and spiritual concepts such as heaven, angels, man's soul, and hell cannot be observed or measured; thus they are beyond the domain of science. These things are part of a person's faith.

within the realm of science. **(2)** The problem must lend itself to a controlled experiment or survey. If the variables cannot be controlled, then the accuracy of the results cannot be certain.

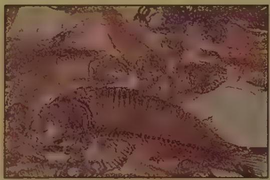
4. Completely controlled experiments yield accurate experimental results. Experimental results differ because the variables differ; accurate results can be found and accurate conclusions obtained only if the change in variables is known. The control group is not exposed to the experimental variable; the experimental group is exposed.

Use this table to present the limitations of science. They are discussed and illustrated in the text. Having the table should relieve the students of writing out the basics; they can carefully listen and note details and explanations.

Visual 1B-1 is a list of the limitations of science similar to the list found on this page. Have students note "Page 18, Table 1B-2" but not copy the table (either from the text or from the visual) into their notes. They already have a copy of the table in their text and are only wasting effort (and not completely paying attention) if they write it down again. Tell them that they should write in their notes those aspects presented and discussed in class that are not represented in the text. This form of note taking is recommended.

1B-2 The Limitations of Science

- Science must deal with observable, measurable phenomena.
- Science can only describe not explain.
- No experiment can be completely controlled.
- Observations may be faulty.
- Man's beliefs affect his judgment.
- Science must deal with repeatable results.
- Science cannot deal with values or morals.
- Science cannot prove or disprove a universal statement.
- Science cannot establish truth.



What scientifically could be said about these?

Another problem scientists often have is being biased. A **bias** is what someone wants to believe. A scientist employed by a tobacco company to research the effects of smoking would tend to emphasize results that would please his employer and overlook results that would show tobacco harmful. Since a scientist must choose an answer, his answer will likely reflect his bias.

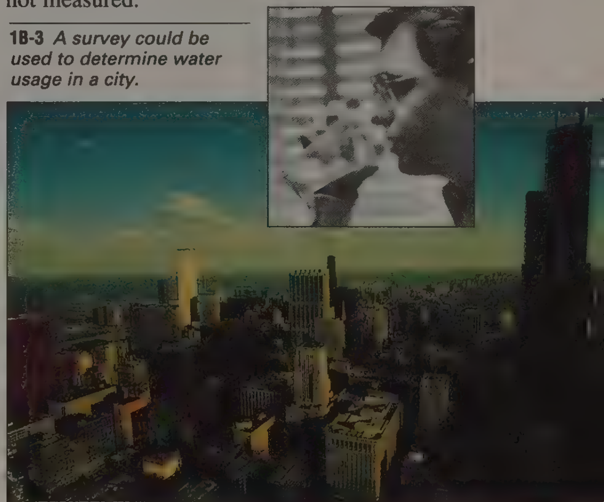
Limitations of the results of the scientific method

Since it is impossible to limit the variables completely in any experiment or survey, the *exact* answer (absolute answer) is not obtainable. Even if you did obtain the exact answer, it would be so hidden in a group of other answers that it would be unrecognizable. Scientists then must *choose* the best answer to a problem. A valid choice is one which is usable because it is supported by repetitions of the experiment and because it can be used to predict future answers in similar situations. But just because an answer is valid does not make it correct.

Information gained by the scientific method is *workable* if it can be used in other circumstances. If a piece of information cannot be used to predict outcomes in similar situations, the information lacks **workability.** For example, if laboratory experiments support the hypothesis that a certain type of plant needs "chemical X" to grow, but in a field these plants grow equally well with or without "chemical X," the results of the experiment are not workable. The results may be valid for plants grown in the laboratory, but in the field some factor (something in the soil or air, or some other condition) causes the plants to grow without "chemical X." In this case the scientist has a piece of information that may be valid but cannot be used to predict the plant's growth in other situations. His information lacks workability.

Suppose it is necessary to find out how much water people in the United States drink per day. This fact is to be used to help project the country's water needs for the next twenty years. A survey is taken of one hundred people living in the Chicago area. If the survey is taken several times in that area with similar results, the results can be called valid. But there is still a good chance that the workability of the information is low. Without many other surveys in other areas, no one can be sure that Chicago is typical of the whole country. Highly valid results of a survey or experiment may be unworkable if the survey or experiment is not typical or if it included conditions that were not measured.

1B-3 *A survey could be used to determine water usage in a city.*

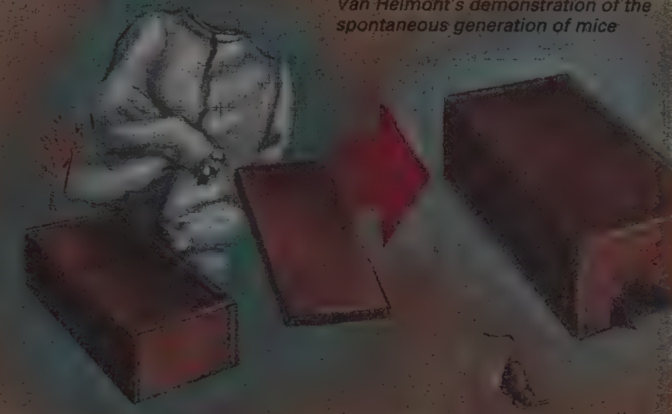


Spontaneous Generation and the Scientific Method

Spontaneous generation, the concept that organisms come to life from nonliving substances (see pages 6-7), was considered an acceptable scientific theory by many people until the mid-1800s. Let us look at two reasons that this belief held on for so long.

In Genesis 1 God spontaneously created organisms out of the earth. Many people assumed that God continued to do so ever since. Those who did not believe in spontaneous generation were accused of doubting God's Word, bordering on heresy. Even today, many people similarly try to use Scripture to support their purposes. We must conform our beliefs to the Bible, not conform the Bible to our beliefs. The supporters of spontaneous generation ignored the Scripture passages that tell us that God finished creation (Gen. 2:1-3) and that organisms reproduce after their own kind (Gen. 1:24-25).

Another reason that some people continued to believe in spontaneous generation of some organisms was the faulty use of the scientific method. To better understand the scientific method and its proper application, we will now consider examples of its use and misuse. The following examples describe some of the more interesting experiments dealing with spontaneous generation and also with **biogenesis,*** the concept that only living things can generate living things.



Van Helmont's demonstration of the spontaneous generation of mice

Jean Baptist van Helmont

Jean Baptist van Helmont (ca. 1600) proposed that mice could be spontaneously generated in at least 21 days by putting a sweaty shirt and grains of wheat in a dusty box. The sweat supposedly supplied the *active principle* which caused the wheat grains and dust in the box to become mice. Every time van Helmont conducted the experiment, he found mice gnawing out from the box within 21 days.

The design of the experiment, however, was faulty. Van Helmont failed to take into account that the mice might be gnawing *into* the box. What could van Helmont have done to limit the number of variables? He was attempting to support his widely-accepted belief. Since his results supported his belief, he did not see the need to restructure his experiment.

Francesco Redi

Francesco Redi (ca. 1600), a poet and physician, also considered the concept of spontaneous generation. Aristotle's statements that maggots and flies spontaneously arose from rotting flesh and slime were contrary to what Redi had observed in nature. Redi believed that the decaying matter and slime served only as the material in which the organisms were growing and that the animals thought to be spontaneously generated were actually the results of biogenesis.

In order to support his belief, Redi devised a set of experiments. Redi placed dead fish, veal, dead eels, and pieces of snake in eight jars. He then placed paper covers securely over one set of jars (the experimental group) and left the other set open (the control group). The two sets of jars were alike ex-

biogenesis: bio- (life) + -genesis (Gk. GENESIS, beginning)

This Facet contains supplemental material which should be studied by most students. Consider having the students read the material, and then cover the material in just a few statements. This Facet presents the use of the scientific method (by looking at errors as well as good uses of the method). This Facet is also designed to help students appreciate the growth of scientific knowledge in light of bias against it. Cover this Facet in a class lecture by asking questions after the students have read it.

The term **biogenesis** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

What were the problems with van Helmont's experiments? *(multiple variables [mice gnawing into and out of the box]; inadequate observation or recording of data [if he had watched closely enough, he would have seen mice gnawing in]; bias [he stopped experimentation when the results supported his belief])* It is easy to condemn him now, but at the time, even conducting such an experiment was almost unheard of (see *A History of Scientific Thinking*, p. 648).

Analyze Redi's first set of experiments. Why did he set up open and closed sets of jars? *(to have a control group)* Which was the control group? *(open jars)* What was the single variable? *(He had two–air entering jars, flies entering jars. This necessitated the next experiment.)*

Francesco Redi (right) and his experiment to disprove the spontaneous generation of flies

First experiment: Redi used a set of open and a set of closed jars

Second experiment: Redi used a set of jars covered with nets.

cept for a single variable: the covers which prohibited the entrance of flies. In a few days, flies and maggots were found in the open jars, but no flies or maggots were found in the sealed jars. Redi's experiment supported his hypothesis.

If Redi had been satisfied and had stopped his experiment at this point, he would have been criticized. Supporters of spontaneous generation would have said that since air (which they believed necessary for spontaneous generation) had been cut off by sealing the jars, Redi had prevented spontaneous generation. Redi's experiment had a double variable: the presence of flies and the presence of air. Redi therefore conducted other experiments. He set up the jars as before, but this time, rather than sealing the experimental jars, he covered them with "fine Venetian net" which would permit air but not flies into the jars. In a few days the open jars had flies and maggots in them. Although flies were attracted to the closed jars and had even laid eggs on top of the net, no maggots or flies were inside the jars.

Redi repeated his experiment in different locations, using different substances in the jars, but he always obtained the same results.

Evidence against the spontaneous generation of flies was shown by these simple, well-designed experiments. Nothing was conclusively proved; no absolute truth was gained; but the experiments produced valid support for biogenesis.

John Needham and Lazzaro Spallanzani

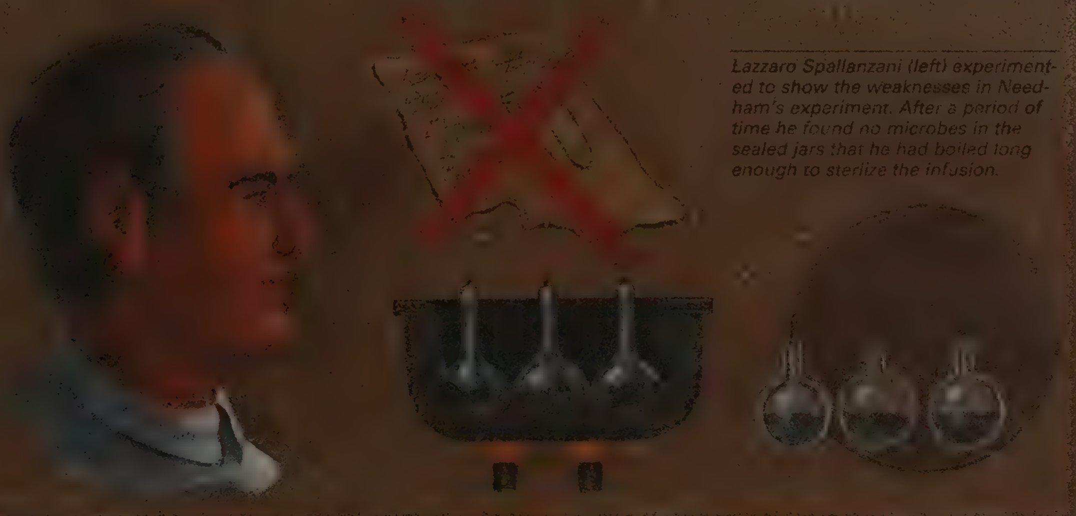
John Needham's experiments, which supported his ideas about spontaneous generation, were described earlier in this chapter. The growth of microbes in infusions that Needham assumed to be *sterile* (without living material present) was held to be proof of the spontaneous generation of these tiny organisms. After all, he reasoned, where could the microbes have come from? They were not like Redi's flies; they could not have traveled into the infusion.

About 25 yr. after Needham's experiments, the Italian scientist Lazzaro Spallanzani (ca. 1700) pointed out weaknesses in them. Needham had not boiled the broth long enough to destroy all the microbes that were already in his flasks, and the stoppers were not tight enough to prevent air-borne microbes from entering. Spallanzani was convinced that these two oversights were not enough to account for the microbes in Needham's infusions.

To support his opinion, Spallanzani conducted a series of experiments. He placed various infusions in glass flasks and sealed the flasks by heating them and fusing the tops. He then placed the sealed flasks in boiling water for one hour to sterilize them. After several days he opened each flask, and none of the infusions contained living organisms.

Spallanzani's experiment, however, was challenged. Since he had boiled the infusions for a long time, some who still believed in spontaneous generation said that he had destroyed the "active principle" in the infusions. Spallanzani then devised another set of experiments. He made several infusions and divided them into four identical groups. One group he boiled for half an hour; another group, for an hour; the third group, for an hour and a half; and the last group, for two hours. All of them he left open. If boiling destroyed the active principle, he should find the fewest organisms in the infusions that were boiled the longest.

After eight days he examined the infusions. Microbes were present in all of them; but the numbers and types of organisms varied. In all but one of them he found that



Lazzaro Spallanzani (left) experimented to show the weaknesses in Needham's experiment. After a period of time he found no microbes in the sealed jars that he had boiled long enough to sterilize the infusion.

Review Needham's experiment, pages 7-8. Ask students what Spallanzani's objections were and whether they were valid. Analyze Spallanzani's first and second experiments, carefully pointing out errors as well as sound logic.

Pasteur's need to conduct a preliminary experiment is quite often reflected in scientific pursuits today. Direct the class in analyzing Pasteur's two experiments. The results of the first experiment lend support to the conclusion of the second experiment.

Spallanzani's experiment to demonstrate that boiling did not hamper the growth of microbes involved infusions boiled for different lengths of time.

the infusions that were boiled the longest had the most organisms. Rather than destroying the active principle, longer boiling had dissolved more of the material, making the infusion better for the growth of microbes.

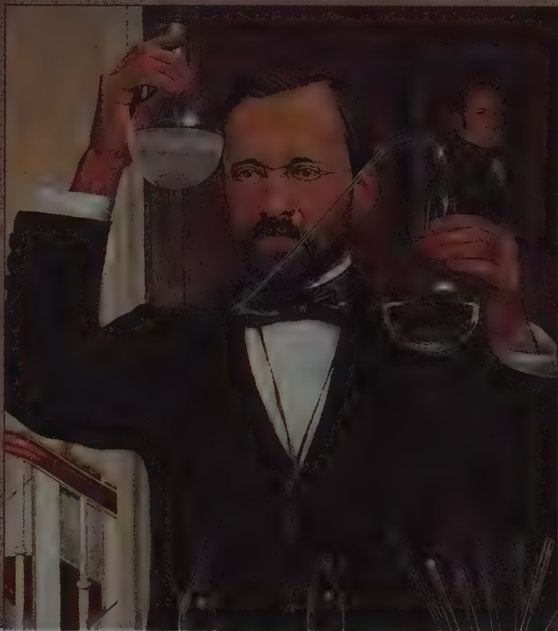
For the next century those who believed in the spontaneous generation of microbes ridiculed those who believed that the microbes in an infusion came from microbes in the air, or their "seeds," as Spallanzani had called them. Since microbes in the air were invisible, most people assumed that there were none there.

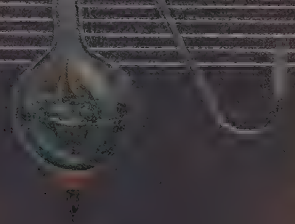
Most of the respected scientists of the 1600s and the 1700s believed in spontaneous generation, but few, if any, devised experiments to support it. They were content to believe in spontaneous generation and quoted one another and the ancients to support their beliefs.

Louis Pasteur

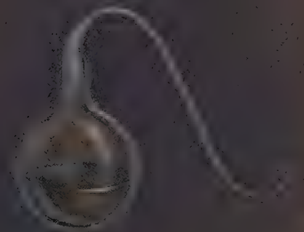
Louis Pasteur (ca. 1800), a French chemistry professor, became interested in the spontaneous generation controversy. Pasteur believed that spontaneous generation was a myth, so he devised a series of experiments which to this day are of unquestioned validity.

One series of experiments was designed to support the idea that microbes are carried in the air. Pasteur prepared several sets of infusions and sealed them in flasks. He then sterilized the infusions by boiling. He opened one set of infusions along a dusty road, another set in a forest, and other sets in other different places. Later, Pasteur examined the infusions and found that those opened in dusty places contained abundant and varied microbes. Those that were exposed to "cleaner air," like the set opened on a mountain, had fewer and different microbes. These results supported his belief that microbes are carried in the air.

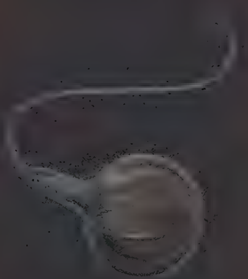




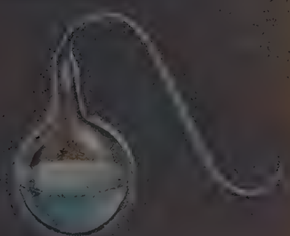
Infusion heated to sterilize it.



Air entered but microbes were trapped in neck. Infusions remained microbe-free for years.



When flask tilted, microbes in trap entered infusion.



The infusion would support biogenesis.

Pasteur's famous swan-necked flask experiment dealt the final blow to the belief in the spontaneous generation of microbes. Pasteur prepared a sugar-and-yeast infusion, put it in a flask, and then bent the neck of the flask so that it formed a long S-shaped curve. He then heated the infusion to sterilize it. The boiling forced air and water vapor out of the flask, but air was able to return freely through the open neck. Pasteur reasoned that the dust and microbes that entered with the air would be trapped in the lower bend of the long neck.

His reasoning was correct, for he found that infusions prepared in this way would remain sterile for over a year. If, however, the flasks were tipped so that the dust particles trapped in the neck could enter the infusion, microbes developed quickly. Though the infusion was still capable of supporting life, life did not spontaneously generate in it.

Spontaneous generation today

After Pasteur's swan-necked flask experiment and thousands of other experiments supporting biogenesis, one might expect most people to reject spontaneous generation. Yet many scientists who believe in biogenesis also believe in evolution and thus are forced to accept the concept of spontaneous generation.

Even today many scientists attempt to prove that the various substances found in living things are formed outside a living organism; if these substances can be brought together and properly arranged, they will form a living thing that can reproduce and evolve into the various organisms now alive. These scientists are trying to obtain data to support the supposed spontaneous generation of life. They would be quick to agree that spontaneous generation is not taking place today, but they are working hard to try to make it

happen in a laboratory. If they can create life, they think they can support their belief in life's beginning without God. But spontaneous generation has never been successfully demonstrated, not even in a laboratory.

Review questions on page 24.

Finding a single exception to a universal statement disproves the whole statement.

Things that cannot be done using the scientific method

People sometimes expect to be able to use science to make decisions. Science may, for example, be used to devise a chemical that, if put into a city's water supply, would kill everyone who drank it. Deciding to put the chemical in a city's water, however, is not in the realm of science. Value judgments and moral decisions must be made by men, not science.

Scientific investigations cannot prove or disprove a universal statement. A universal statement includes a word such as "all," "always," "no," or "never" which makes the statement impossible to prove through experimentation. To say, for example, that all wooly mammoths are extinct cannot be proved. Every place in the world would have to be checked at the same time, since the wooly mammoths could change locations. The more limited statement that no living wooly mammoths were in your backyard at noon yesterday may be valid, depending on the size of your yard and how many people were observing.

Science cannot be used to establish truth. The fact that man can observe something and measure it, and do so repeatedly, does not *prove* his hypothesis. The results of the scientific method may only *support* or *not support* a hypothesis. The more support a hypothesis has, the more valid it is assumed to be. But no amount of scientific experimentation, or any other type of work, can prove beyond doubt any statement.

Review Questions 1B-2

1. Why is workability an important criterion for scientific knowledge?
2. Why can science not prove a universal statement?
3. What is the difference between the term *valid* and the term *proved?* (Hint: Scientists are seeking *predictable* and *workable* answers to problems.)
4. List and describe eight limitations of science.
5. List two areas of human concern in which the scientific method of problem solving is useless and explain why.
6. Why is a large problem more difficult to deal with than a small one when using the scientific method?

Facet 1B-1: Spontaneous Generation and the Scientific Method, pages 19-23

1. List several reasons why people living before the 1900s believed in spontaneous generation.
2. What could van Helmont have done to obtain more valid results from his experiment with the spontaneous generation of mice? How would these adjustments have altered his results?
3. Why was Redi's second set of experiments with the spontaneous generation of flies necessary? Could he have eliminated the first experiments and still obtained the same validity for the second experiments? Explain.
4. Why was Spallanzani's first experiment with spontaneous generation of microbes challenged? In what way did his second experiment add validity to his first set?
5. Explain how Pasteur's first experiment (open sterile infusions in different places) was significant in supporting biogenesis.

Answers–Review Questions 1B-2

1. Workability is necessary for the information to be useful for predicting outcomes in similar situations.
2. In order to prove such absolute statements, every situation or area of the world would have to be checked at the same time to determine the absoluteness of the statement. This task cannot be performed by humans.
3. Something that is valid is accurate and reliable; it is supported by repeated experiments and may be true, but one is not sure of that. Only those things which are revealed as truth by God can be accepted as absolute truth.
4. See Table 1B-2 on p. 18.
5. Value judgments such as beauty, enjoyment, and intrinsic worth are beyond the scope of science. These cannot be measured since they are not physical phenomena and thus cannot be dealt with scientifically.
6. Larger problems have more variables than do smaller problems. These variables must be controlled in order to have valid results.

Answers–Facet 1B-1

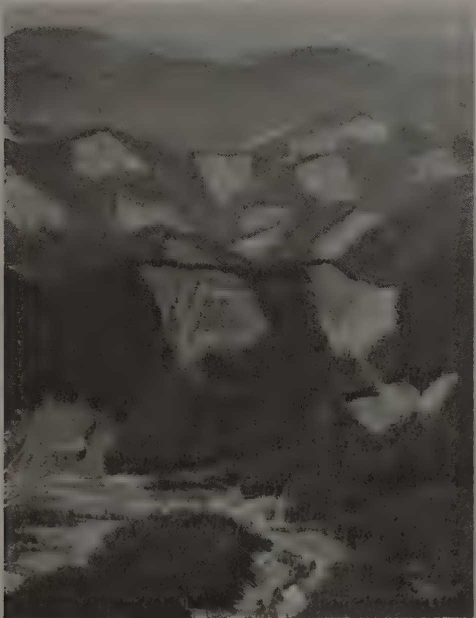
1. Some people cited the passage in Scripture in which God created living things out of the ground to support their belief in spontaneous generation. The fact that they had not observed many organisms reproducing supported their belief. The experiments of people like van Helmont and Needham also supported their beliefs.
2. He could have observed more closely and seen the mice gnawing into the box. He could have prevented mice from getting to the box (put it in a cage). The close observation of these experiments would probably have forced him to change his opinion.
3. The second experiment was needed because his first experiment had two vari-

Science and the Christian

In the first part of this chapter, science was defined as a body of facts that man has gathered from observing the physical universe. Such a simple definition is not really adequate to define science and its many ramifications. Other possible definitions of science include these:

- the organized total of man's knowledge gained through observation;
- knowledge obtained through investigation;
- man's efforts to understand God's creation.

These valid definitions of science overlap, but each shows aspects of science not seen in the others. They should all probably be used together. The important thing is not to have a series of words to parrot when asked what science is but to have a *working understanding* of what science is, what it can do, and what it cannot do. It is important for the Christian to realize what science is and the limitations of science so that he can see the proper relationship between science, God, and His Word.



Scripture's scientific challenge

No matter how much we Christians look forward to heaven, God has placed us on earth to do His will faithfully while the Lord Jesus prepares our eternal home. Part of doing His will is to "preach the gospel to every creature" (Mark 16:15). Other tasks involve worshiping and praising God, praying, and believing in His name. But the first recorded duty of man was a scientific one. In Genesis 1:28 God told man to subdue the earth and to have dominion over it.

There are two basic methods of subduing and having dominion over anything. If a ruler wants to subdue and dominate a city, he can send his army to destroy the entire city. The city will be subdued, and he will dominate it. But what would he rule? A mass of rubble has no great value. It is better to subdue and dominate without destroying. The better methods may take more time, but they can be just as effective and produce better returns.

Second to the Bible, science is man's principal source of the knowledge that he needs to subdue and to have dominion over the earth without destroying it. Mankind will never completely dominate the earth. Not only does science have many limitations, but also man is a sinful creature and cannot perfectly rule the earth. Not until Christ returns for His thousand-year reign will the earth be completely subdued and dominated. This does not mean that we should not try to properly subdue the earth, but that we should do the best that we can while realizing our limitations.

Consider the problem of heating a home. Man can cut and burn trees to supply his home with warmth, but if man had done so without care, he would have depleted the earth's natural forests long ago. Of course, man has replanted trees to supply future generations with wood to heat their homes. When, where, and how to plant which

1B-4 *Block cutting of timber in Olympic National Forest. One of the modern methods of logging which helps man to obtain lumber without destroying the forest, a renewable resource.*

The material in this section is important to all Christian students. It presents the Christian philosophy of science in terms most young people can understand.

ables. Since the second experiment had a control group (jars with no coverings), it would have been all that was needed. The paper-covered jars were the nonvalid experiment.

4. Spallanzani boiled the infusions so long that people felt he had made them unable to support life. His second experiment demonstrated that life can be supported in infusions that have been boiled a long time.
5. Pasteur's first experiment demonstrated that microbes are carried in the air. By showing that different air contains different microbes, he demonstrated this. His second experiment could have been criticized if he had not shown that microbes enter sterile infusions from the air.

This box contains supplemental material which should be studied by most students. This box presents the difference between pure and applied science: the research and technical methods. The goal is to help students see that there are different kinds and levels of scientific activity. Not all that appears to be scientific is actually scientific.

The terms **pure science, applied science, research method,** and **technical method** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

One possible use of this box is to discuss briefly the contents and then ask students for common examples of what can and cannot be studied, using the scientific method. Another use–construct a verbal example and have students analyze the use of the scientific method. As they do so, draw parallels to the example given in the box.

Science: Pure or Applied

Scientific activities can be classified as pure or applied science. This is not a value judgment regarding rightness, but a judgment of how *workable* that science has become in our society.

Pure science is knowledge that scientific activities have produced. A scientist may, through experimentation, discover that a particular plant requires a certain nutritive element in order to produce fruit in maximum numbers and size. That knowledge, as well as the work behind its discovery, is pure science.

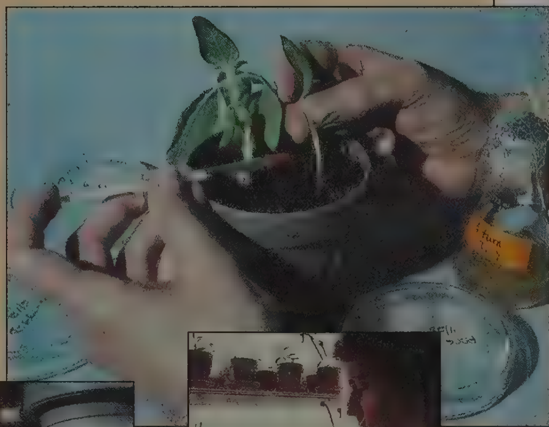
Applied science is *using* knowledge gained through scientific activities. When a person uses the knowledge of the nutritive requirements of a plant in order to supply the proper amounts of that nutrient to a field of plants to obtain a more abundant harvest, the knowledge has become applied science.

Two different types of scientific activities have been involved in the above example. The first scientist used the **research method.** He recorded, classified, and analyzed data; chose an answer and verified it; and then made predictions about the nutritive element and the plant. He is a *research scientist* and has used the scientific method of thinking to discover knowledge.

The person who follows the instructions of the research scientist in order to apply the correct amount of nutrient to a field of plants is a *technician.* A technician, in this case, uses the techniques prescribed by the research scientist to predict the nutrient needs of a particular field of plants. The use of prescribed techniques to obtain information about a particular example is the second type of scientific activity, called the **technical method.**

A research scientist may devise a test to determine the presence of a certain chemical in human urine. The person in the laboratory who follows the instructions of the research scientist to test human urine samples is a *laboratory technician.* Both research scientists and technicians are necessary. Without research, scientific knowledge is not gained. Without technicians, scientific knowledge is not used.

Study these pictures. Can you tell which of these people are using the research method and which are using the technical method? Can you tell which illustrates pure science and which illustrates applied science? The answers are on page 29.



1B-5 *This computer of the 1950s contained about 800 transistors and, although an improvement over large vacuum tube computers, was less powerful than computers found in many homes today. As man gains the use of better tools, his scientific accuracy may improve, but wise use of information happens only as he bases decisions on God's Word.*

trees for quickest production of lumber is information not given in Scripture. Yet man, using his God-given intelligence, can determine how best to grow trees.

As world population continues to grow, however, man could run out of wood despite reforestation. Other sources of energy, such as natural gas, oil, solar power, or electricity made from flowing water or nuclear power, have been used to heat homes in scientifically advanced countries. Less than a hundred years ago these heating methods were only ideas. Today, through scientific endeavors, they are commonplace.

God expects man to use science

The physical world is made of substances which operate under God-ordained laws. Scripture teaches that God created the world and sustains it. Man is to subdue and have dominion over it. If he uses his God-given intelligence, he can subdue and have dominion over the world without destroying it. If he ignores what science can teach, he will have wasted two God-given gifts: the earth and his intelligence.

God has revealed in the Bible all the *spiritual* knowledge we need. But God did not reveal all the *scientific* knowledge mankind would need in order to exist on the earth until His return. God, according to His timing, permits man to discover scientific knowledge. For example, beasts of burden, such as horses and donkeys, cannot do the things trains can do. Moreover, trains by themselves are not able to do what trucks and cars do today. God has *permitted* man, through science, to discover the knowledge he needs to build things he can use.

Some people feel that science is basically bad and attempt to return to "natural" methods of doing things. Some people even feel that returning to the old ways is more godly. But the old way of doing things is not necessarily the best way. For example, the fact that our great-grandfathers used candles and torches for light does not make those light sources better than electric lights. In previous times candles and torches were the best methods that man's knowledge had devised, but scientific investigation has supplied additional knowledge about illumination. There is nothing wrong with our using that information. Running from scientific ideas and returning to old methods of doing things is not turning back to God. Instead, it is the burying of scientific talents, much like the burying of spiritual talents spoken of in Matthew 25:14-30.

"Old-fashioned" ways of doing things may have nostalgic appeal, but they are not necessarily best just because they are familiar. Our forefathers' ways often deserved condemnation. Man is right only when he does right, no matter in what era he lives. Perhaps moral ethics were better "way back when," but cooking on wood-burning stoves and using kerosene lamps will not restore those high moral standards. Many Christians have made this error in logic.

Some improper attitudes of Christians toward science

A wrong attitude toward science is to believe that science is anti-God. Since science is the discovering of usable information about God's creation, science is not inherently bad. Scientific information can be used for good or bad purposes, but science does not decide how information is used. Men do. Science is not evil just because men have abused scientific knowledge.

It is interesting that when cars were first becoming widely used, some Christians condemned them, saying that these new-fangled scientific inventions were going to cause man to sin. A person

Many Christians manifest these improper attitudes toward science. The supposition that the space program is sinful is a good example. It may not be wise to spend vast amounts of time and money on the space program, but investigating God's creation is not inherently sinful.

See *scientism* (p. 171).

can sin by using a car, but simply *having* the car is not sin; it is man's *sinful use* of the car that can be wrong. A car, rightly used, can be a tool of blessing. The same is true of most modern conveniences, like television and record players.

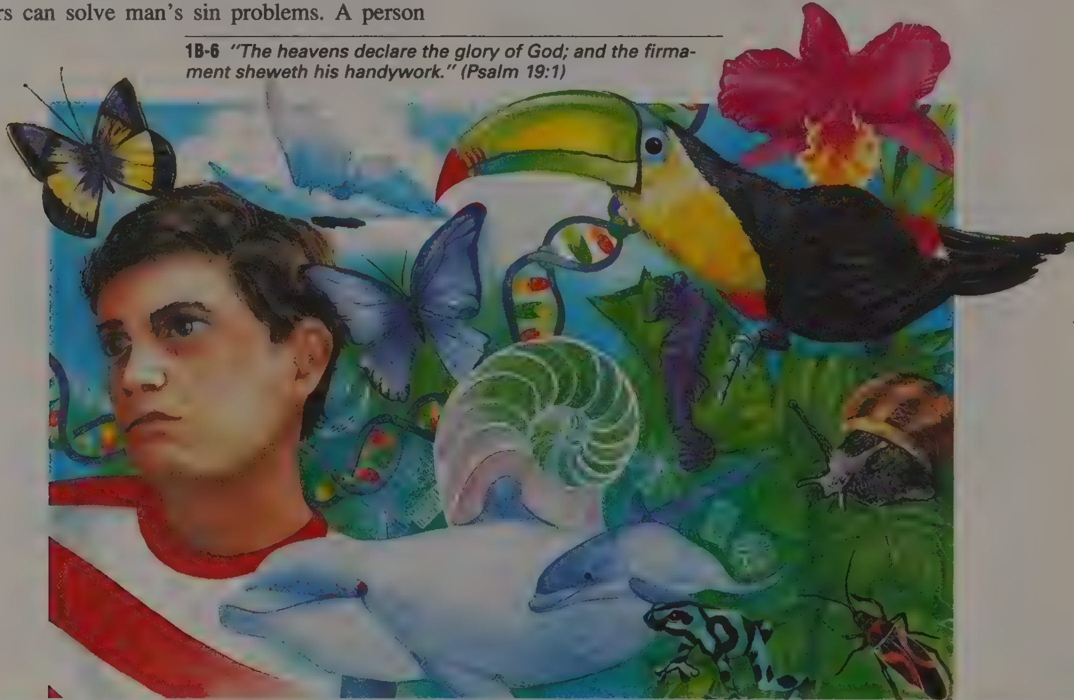
It is wrong for a Christian to think that scientific achievements will replace faith in God. Although scientific investigations cannot supply all the answers man wants when he wants them, and although the answer may be wrong and may need changing as more information is obtained, science can and does supply workable answers. That fact may cause some people to place their faith in science rather than God. They look to science to solve all their problems, but it cannot do that. Science supplies information which can solve *physical* problems. The problems with which science cannot deal are man's real problems: science cannot solve the guilt problem caused by sin; science cannot save a man from hell. Only faith in the Lord Jesus Christ and the salvation He offers can solve man's sin problems. A person who believes that man's wisdom can solve these problems is believing something which Scripture says is not true (I Cor. 3:19).

A proper Christian attitude toward science

Since science is a tool used by man to discover useful knowledge about God's creation, science itself is not good or bad. Men use or abuse knowledge gained by scientific investigations. It is wrong, therefore, for a Christian to condemn science as being anti-God or to fear science, believing it can destroy man's faith in God. It is also wrong for a Christian to ignore science. Man's intelligent use of God's creation is part of subduing and having dominion over the earth.

The psalmist states in Psalm 19:1, "The heavens declare the glory of God; and the firmament sheweth his handywork." God's power and majesty are revealed in what He has created. The person who looks carefully at creation can know more about the God Who created it.

1B-6 *"The heavens declare the glory of God; and the firmament sheweth his handywork." (Psalm 19:1)*



Answers–Review Questions 1B-3

1. Answers will vary. **(1)** Science is a tool used to discover useful knowledge about God's creation. **(2)** Science can be a means of subduing the earth without destroying it. **(3)** Science, by examining nature, reveals more information about the God who created it. **(4)** A proper study of science can be used for the Lord to benefit others. **(5)** Science provides knowledge that man needs in order to exist on earth.
2. It enables him to see the wonder of God's creation and view the greatness of God. This causes greater praise and admiration (worship) of God.
3. In pure science, a research scientist seeks to find answers to questions by using the scientific method. In applied science, a technician uses methods that have been prescribed to him to determine something about a specific problem. For example, a research scientist uses pure science to determine that bacteria X in the blood is the cause of disease Q. A technician in a hospital follows prescribed techniques to determine whether a patient has disease Q by finding bacteria X in the patient's blood.
4. A person using the research method is attempting to find answers by using the scientific method. A person using the technical method is following prescribed techniques to find out something about an individual case or to change an individual case or situation.

Answers–Thought Questions

1. The scientific method deals solely with observable and measurable phenomena (the physical realm). The factors in value or moral judgments cannot be observed or measured; they do not fall within the physical realm and therefore cannot be dealt with through the scientific method.
2. It is ideal for an experiment to be limited to one variable so that the results

True **worship** can be defined as man's recognizing his insignificance and turning his thoughts in love, reverence, adoration, and obedience to the almighty God. Worship does not require a church building, a preacher, or soft organ music. All too often worship does not take place even with all these helps. Worship takes place when *you* seek to *know* and *obey* God. Worship can and does take place when men look at the creation and see the God who designed, created, and sustains it. True scientific knowledge can enhance your worship by giving you more insight into the wonders of God's creation.

Answer to questions on page 26 All scientists on these pages could be using the technical method and therefore would be technicians. However, if the data they obtain is recorded, classified, and analyzed in order to choose an answer which will then be verified–or if the data is used to verify some previously chosen answer to a problem or survey, they are using the research method and therefore would be research scientists. In other words, the activity itself is not as important as the purpose for the results in determining the difference between research and technical methods.

Studying the physical world can be worship only if it is approached with a worshipful attitude. Worldly scientists do not worship the Creator as they learn of His creation, for they do not recognize the physical world as a revelation of the Creator. If one does, he can worship Him as he learns of the intricacies of His creation.

Biological Terms

scientific method

Using the Scientific Method
- research
- hypothesis
- experiment
- survey
- data
- controlled experiment
- experimental variable
- control group
- experimental group

The Limits of Science
- bias
- workability

Science and the Christian
- pure science
- applied science
- research method
- technical method
- worship

Facet
- biogenesis

Review Questions 1B-3

1. List five points that could be considered in developing a proper Christian attitude toward science.
2. In what way can scientific knowledge aid a person in his worship of the Creator?
3. What is the relationship between pure science and applied science? Give an example of each.
4. What is the relationship between the research method and the technical method of science?

Thought Questions

1. Why cannot the scientific method be used to make a judgment of values or morals?
2. Why is it important to have a single variable between a control group and an experimental group? What happens if there is more than one variable?
3. Science can only describe, not explain. Why is this statement true?
4. Occasionally it is reported that a scientist has performed an experiment which *proves* a passage of Scripture. Is this possible? Why or why not?
5. Some people look to science as a god. Since scientists have supplied the knowledge to heal many diseases and have used scientific information to produce many conveniences, they look to science to cure all their problems. Why is this view of science unacceptable to a Christian?
6. Some Christians turn away from anything that appears scientific. Since they do not understand science and cannot find most scientific facts in the Bible, they believe that science is anti-God. Give five Biblically based reasons that these Christians should reconsider their opinions.

are as accurate and reliable as possible. As the number of variables increases, the validity of the results decreases.

3. Science can only describe because science is based on human abilities and experiences. Therefore, science cannot explain any natural phenomenon because humans cannot know the origin of anything (except as revealed by God's Word) and can only speculate as to reasons or causes of physical phenomena.
4. No. It is impossible to prove any part of the Bible in the sense of repeating a particular event. However, scientific information may confirm some Scripture passages. The Bible is always accurate when it deals with science, and true science and the Bible confirm each other.
5. Christians are supposed to depend on God and His truth, not on man and his knowledge, for the solutions to their problems. Science cannot solve all problems; it is based on human experience and ability. Since humans are fallible, science, too, is fallible.
6. Answers will vary. (1) Christians need to subdue and to have dominion over the earth intelligently. (2) Christians should desire to understand and admire God by a study of His creation. (3) To ignore science is to ignore a gift from God–His beautiful creation. (4) Christians need to employ scientific information in their attempts to serve others. (5) Christians need to have a proper perspective of themselves in relation to the entire universe.

assimilation: as- (L. AD, to) + -similation (SIMILIS, like)

Use this discussion as an etymology using *bios* and *logos*.

Display a group of 15 to 20 items, including both living and dead items in various states (such as a rock, potted plant, dried plant, cut flower, alcohol, stuffed animal, living fish, dried twig, twig with leaves, soap, seeds, electric motor, battery, and glass). Begin by asking students to tell you if the item is alive or dead. Hold up each item, describe it (humorously if possible), and then ask for a consensus (vote if necessary) about classifying it with the living or dead group. Ask students to compare living things with dead things. List the attributes of life, remembering that dead things may have some of these attributes, but not all of them. Finally, classify items into three groups: living, organic dead, and inorganic. This is best done before students are assigned to read this section of material.

See the comments on *vitalism* (p. 58). Life is not a substance living things have and dead things do not have. Life is more than the sum of the chemicals that make up living things.

1c–Biology and the Study of Life

Biology is often defined by its Greek word origin: *bios*, which means ''life'' or ''living,'' and *logos*, which literally means ''word'' but has come to mean ''study of'' or ''science of.'' The previous sections of this chapter have discussed the term *science*. We now turn our attention to the other portion of the definition of the term *biology: living*. What does it mean to be alive? Just as there is no set definition for *science*, no set definition can be given which will adequately describe life.

The Attributes of Life

Rather than study definitions, let us look first at a list of the *attributes of life*. This list does not include all the attributes, but it does present the major characteristics of living things. Since these attributes describe a very complex phenomenon–the **living condition**–they necessarily contain overlapping ideas.

Do not think that anything that possesses a few of these attributes is alive. Living things have *all* these attributes. Nonliving things, such as machines, computers, light bulbs, and chemicals, may have one or several of these attributes, but only those things which have all of them are alive.

❑ **Movement** Normally one thinks of movement as motion from one place to another. Actually, moving from place to place is *locomotion*. Plants, most fungi, many bacteria, and even some animals cannot carry on locomotion, but they are alive and do exhibit movement.

Movement may be **internal movement** as well as locomotion. Even when you are perfectly still, blood is moving in your veins. Until you die, small structures will constantly be moving inside the cells of your body, even when your body is at rest. Plants move water internally, dissolve minerals, and process foods. Even a stationary, single-celled organism carries on internal movement.

❑ **Growth** Though rocks or buildings may be said to grow, they are nonliving things and grow only in the sense that more material is added to them. But in order to increase the size of a brain, one cannot similarly add more brain substance directly into the skull. Living things do not grow that way. Organisms grow by **assimilation*** (uh SIM uh LAY shun)–assembling the component parts which make up their living material. Growth is *achieved by* an organism, not *done to* an organism.

Growth does not always affect the size of an organism. Growth is often the replacement of worn-out cells. An adult, as a rule, does not continue to grow in size but does grow new cells and parts of cells to replace older cells until he dies.

❑ **Reproduction** At one time or another during its life span, every normal living thing is capable of reproduction. **Reproduction** is the making of another organism which has characteristics and limitations similar to the original. Splitting a rock in two is not reproduction since the two halves cannot become like the original. Some small organisms do reproduce by splitting in two. But unlike the rock, each new organism has the capability to become like its parents, just as a puppy becomes like its parents. Puppies are not ''half dogs.'' They are small dogs that have inherited a dog's characteristics and limitations.

Although a puppy has been nourished by its mother's body, very little of the puppy (only the

1c–Biology and the Study of Life

Notes–Chapter 1C

Chapter 1C begins with a discussion of what life is. This is presented as a list of the attributes of life. It then compares physical life and spiritual life. After determining that life is a condition rather than a substance, the chapter progresses to a discussion of how to study life. The microscope as a basic tool is presented as well as other methods of observing life.

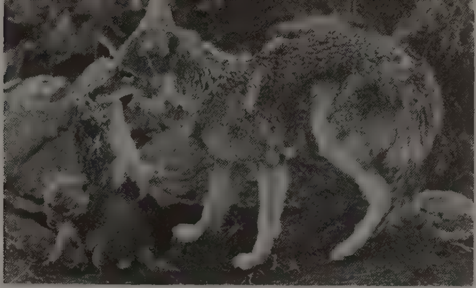
Some of the difficulties of using the scientific method to study the condition called *physical life* are presented. The chapter ends with a discussion of the idea that science is not infallible. It is not truth as Scripture is truth, but it is the best process man has to find answers to physical problems.

Facet–Chapter 1C

The Facet *Biological Research Techniques* presents simple explanations of various common techniques used in biological research. Some are more difficult than others. Omit this Facet or have the students read it; then choose several of the techniques they are to be responsible for.

Objectives–Chapter 1C

- ❑ List and describe the attributes of life.
- ❑ Identify the parts of the light microscope. Demonstrate an ability to use the microscope.
- ❑ Compare the centimeter, millimeter, micrometer, nanometer, and angstrom.
- ❑ Recognize the problems inherent in the scientific study of life.
- ❑ Explain the relationship between science and scientific models.



1C-1 *The coyote pup will be similar to, but not exactly like its mother. There are limits to the amount of possible variations it can have.*

original egg and sperm cells) was actually part of the mother and the father. After growing, the puppy will be similar to its parents.

Reproduction of living things is not making duplicates from a mold. A mother dog is not a mold for her puppies. She and the father dog have given the puppies the genetic information necessary for them to grow into dogs.

❑ **Comes from similar preexisting life** As a result of careful observations of controlled experiments and natural conditions, *biogenesis* is now generally accepted. Since all organisms reproduce, there is no need for spontaneous generation.

The idea that life comes from *similar* life is important: oak trees reproduce oak trees, and cats reproduce cats. The idea of oak trees reproducing cats is absurd. (However, in a roundabout way, this idea is similar to what evolutionists believe.) It is true that no kitten will be exactly like its parents. Some kittens may be slightly larger or smaller or have different colors, depending on the genetic information given to them by their parents. These differences, some minor and unobservable and some very noticeable, are termed **variations.** But variations are limited. The eventual adult size of a kitten, for example, is limited to a certain range. The genetic information inherited by a kitten (along with its diet, exercise, and physical surroundings) will determine what point in that range it will attain.

❑ **Similar chemical make-up** All living things are made up of the same basic chemical elements in similar compounds. Since all organisms move, grow, reproduce, and come from preexisting life, the idea that all living things have a similar chemical make-up is not surprising.

The substances which living things produce contain varying amounts of carbon and are called **organic** chemicals. The living material of an organism is **protoplasm.** Many organisms, however, produce substances which are nonliving and often remain long after the protoplasm has deteriorated. These nonliving substances are organic but are not alive. The shell of a snail, the hair of your head, and the hoof of a cow are examples of *organic dead* materials. Of course, the body of an organism that has just died can also be considered organic dead material before it decomposes. Those things that are not alive and have never been alive, such as rocks, water, steel, and glass, are considered **inorganic.**

❑ **Made up of cells** Every living thing is made of either a single cell or many cells. Cells, discussed in Chapters 3 and 4, are units of protoplasm which are limited by the membranes they manufacture.

❑ **Irritability** All living things respond somehow to various forces in their environment. **Irritability** is the capacity to respond to stimuli. For example, human beings are highly sensitive to light and respond not only to its intensity, direction, and color but also to the object from which it comes. An earthworm, on the other hand, does not have eyes but merely light-sensitive areas. Though human beings need to respond to what they see, an earthworm merely needs to know if it is in the light or not; in its burrow seeing is not important. Sensing the light, however, the earthworm is aware that it is not in its protective hole and can do something about it. God designed each organism to be sensitive to those conditions in the environment that affect that organism.

❑ **Requires energy** All living things require a constant supply of energy. Humans obtain energy from food. Plants and some other organisms obtain their energy directly from the sun and store it for future use. **Food** can be defined as an organic, energy-containing substance. The energy that plants *store* is in the form of a food. Since

Differences between similar organisms are variations, such as coat color in dogs and cats, amount of milk production in cows, and height in people. Variations are also discussed on page 153. Introduce this idea, but be sure to stress the fact that there are natural limits to this concept.

Stress what food is. "Plant food" is not really food; it is fertilizer. It contains the minerals but not the energy a plant needs. Humans cannot live on only vitamin tablets (containing nutrients, but little or no energy) because they are not food. Plants can survive on nutrients that contain little energy. They get their energy from the sun.

Illustrate the last three attributes of life by taking several identical strips of cardboard and tossing them onto the screen of an overhead projector. Ask the students if this is organized. *(No.)* Repeat several times. Then carefully arrange the strips in a geometric pattern. Ask if this is organized. *(Yes.)* Do several other arrangements, repeating the question. Now ask the students to define organization. Organization is a condition, a relationship among various pieces of a whole.

There are various levels of organization. "Highly organized" means that there are limited variations within the arrangement of the pieces. Note that the more organized the system of the strips of paper is, the more effort went into organizing them. High levels of organization require design. To maintain a high level of organization, the pieces must be static (cemented down or frozen), or they must be reorganized whenever they are disturbed by the elements.

Life is a highly organized system. An organism must constantly reorganize itself to remain alive. This reorganization is why the living condition requires energy. Death occurs when a sufficient number of the significant pieces lose their organization. Since these "unorganized pieces" no longer supply energy to maintain the organization of the other parts, the whole thing falls apart (dies). In time, even those parts that have static organization (such as bones) will either fall apart or be taken apart.

many organisms, like plants, do not eat food, it is not accurate to list "eating" or "requires food" as an attribute of life. Organisms require energy.

❑ **Maintains a high level of organization** Being alive requires that a collection of molecules be *highly organized.* This organized complex of molecules forms the structures of living things. Energy is required to keep these molecules in that organized condition that permits life. As soon as energy is no longer expended to keep the organization, the molecules fall into disorder, and the organism begins to die. Think of it this way: in part, you are a self-assembled mass of what you have eaten; you are being held together in complex order by the energy you have obtained from your food. The Bible puts it this way, "Dust thou art, and unto dust shalt thou return" (Gen. 3:19).

❑ **Faces death** All things that are alive will die. Actually, parts of all living organisms are constantly dying–that is, they are no longer being held in the organized state that permits life to continue. Today thousands of cells in your body will die, and parts of all cells will wear out and cause the cells to die eventually. You are still alive because your body is expending large amounts of energy to produce new cells and to keep alive and in good repair most of the others. If the Lord tarries, however, there will come a time when enough of one type of cell in your body–heart cells, brain cells, liver cells, or whatever kind of cells–will die, and the other living cells in your body will not be able to carry on.

Christ on the Cross, Bob Jones University Collection of Sacred Art.

1C-2
Christ's death paid the price for our sins, so we can have spiritual life.

The living condition

Physical life is not some special element or compound that some objects have and others do not. Life is a *condition,* a state in which something exists. **Life** can be defined as a highly organized cellular condition which is derived from preexisting life; requires energy to carry on processes such as growth, movement, reproduction, and responses; and faces death. It is more important, however, to understand what life is than to memorize a definition.

In the Bible *spiritual life* is often compared to physical life, and the comparison makes sense. The Christian's spiritual life, for example, comes from God's pre-existing spiritual life. Spiritual growth requires the strength (energy) we receive from God as we read and meditate on His Word. We also need His power to reproduce spiritually–that is, to witness to others and bring them into God's family. Our spiritual life is highly organized; we are to do God's will as prescribed for us in the Scripture. We grow in the Spirit only when we are responsive to God's leading.

One of the most notable exceptions to the parallels between our spiritual life and physical life is that Christians do not face spiritual death. Christ has conquered spiritual death; so those who know the Lord will live eternally with Him. Our physical bodies will die and return to dust, for "it is appointed unto men once to die" (Heb. 9:27). But our spiritual, glorified bodies will know no age and face no death.

Review Questions 1C-1

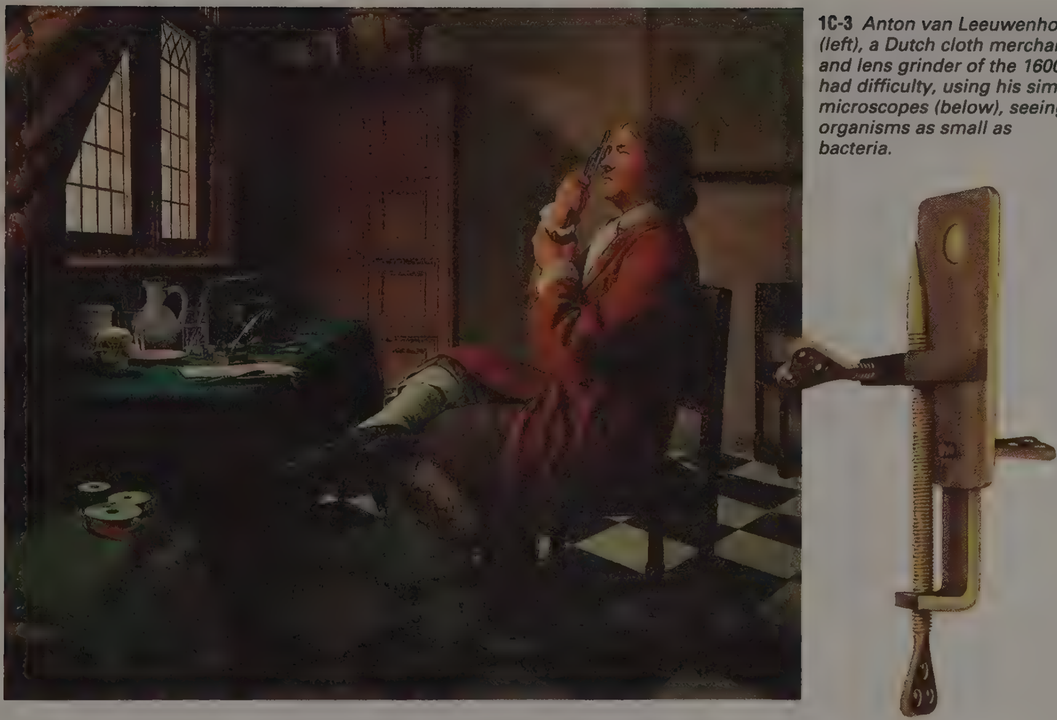
1. List and briefly describe the attributes of life.
2. Why is life best described as a condition?
3. List several characteristics of physical life and parallel characteristics of spiritual life as presented in Scripture.

Students often wish to add "require air" or "need O_2." While this is true for the organisms students are most familiar with, it is not true of some living things. Some bacteria, for example, are killed when exposed to air or oxygen.

A brief challenge about care of the physical and spiritual life would be appropriate here. In explaining our spiritual nature, God frequently compared His children to physically living things. Consider using Psalm 92:12-14.

Answer–Review Questions 1C-1

1. (1) Movement–Locomotion and internal movement are present. (2) Growth–Growth is an organism's assembling the component parts that make up its living materials; done by an organism, not to an organism; not only increases size but also replaces "worn out" structures or tissues. (3) Reproduction–Living organisms must reproduce new, complete organisms similar or identical to the parent or parents; may reproduce sexually, asexually, or by both methods. (4) Comes from similar preexisting life–Organisms reproduce after their kind; biogenesis, not spontaneous generation, occurs. (5) Similar chemical make-up–All living material is protoplasm; many elements are common to all organisms–in particular, organic materials, which contain carbon. (6) Made-up of cells–May be either single-celled or multicellular; cells limited by a membrane. (7) Irritability–Living things respond to various stimuli; sensitive to conditions of environment. (8) Requires energy–Living things take it from food or the sun (in organisms it is generally stored as starch, glycogen, etc.). (9) Maintains high level of organization–Organized complexes of molecules form structures of living organ-



1C-3 *Anton van Leeuwenhoek (left), a Dutch cloth merchant and lens grinder of the 1600s, had difficulty, using his simple microscopes (below), seeing organisms as small as bacteria.*

microscope: micro- (small) + -scope (Gk. SKOPEIN, to see)

The Study of Life

Studying life has always been difficult. Life is a state of being which can cease, leaving the investigator with a set of dead chemicals. Studying these chemicals may reveal what life *has done* but not what *it is*. Finding out what chemicals make up a living body does not reveal much about the life which the body had before the chemicals were separated. Diagrams of a watch can tell an engineer how the watch works; but careful descriptions of the size, shape, color, and even chemical make-up of the various structures of living things tell us little about life processes. A complete set of diagrams of the human body is simply inadequate to describe how it works.

In this section we will look at some of the tools and techniques scientists use to study living things and some of the difficulties they experience as they study life.

The microscope: a tool for biological study

Although a description of an organism's structures is not adequate by itself to explain life, a knowledge of the structures is essential. Unassisted human vision, however, cannot see millions of microbes or the parts of cells which make up an organism. **Microscopes*** aid in studying these tiny structures.

The first microscopes were probably made in the first century A.D. by filling glass balls with water. Glass lenses that were used to magnify structures were introduced in the Middle Ages. A single lens constitutes what is called a *simple microscope*. In about 1590, two Dutch eyeglass makers, the Janssen brothers, mounted two lenses in a set of adjustable tubes. The lens closer to the observer's eye magnified the already enlarged image of the lens closer to the object being observed. Such a microscope, consisting of two lenses or

isms and require energy to maintain organization. (**10**) Faces death–In a gradual, continuing process, certain cells die every day; eventually, vital tissues (such as heart, brain, and nerves) will die, and the organism will die.

2. Life is not a substance or a ''magical force.'' It is a property that certain things possess which is more than the sum of physical parts.
3. Physical life comes from preexisting life. Spiritual life is the gift of God to man (it comes from God, who existed before man). Physical life requires energy. Spiritual life requires power from God–it does not come from within man. Physical life reproduces. The Christian ought to bear fruit spiritually. Physical life is highly organized. Spiritual life should follow God's organization (plan) as revealed in His Word. Physical life requires substances to be assimilated. Spiritual life requires that a Christian assimilate (have become part of himself) the milk and meat of God's Word.

centimeter: centi- (L. CENTUM, hundred) + -meter (Gk. METRON, measure)

millimeter: milli- (L. MILLE, thousand) + -meter (measure)

This box presents the various size measurements used in biology. The material presented in this box is crucial to covering the size relationships given throughout this book.

The terms **centimeter, millimeter, micrometer, nanometer,** and **angstrom** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Appendix C (pp. 666-67) is a brief explanation of the metric system. In this course, students need not perform conversions between metric and English units. Usually both metric and English units appear in this book. It is wise, however, for students to understand the relative sizes of the units of the metric system.

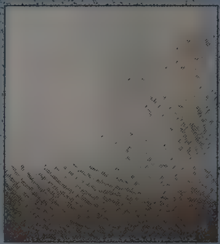
Visual 1C-1 is a diagram of the various size measurements used in biology.

Use the overhead projector and a transparent centimeter ruler to help students see the minuteness of the smaller measurements. Although the students may not know what they are, refer to the structures on pages 34-35 to show some significant size variations.

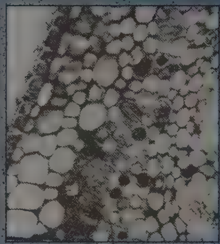
Biological Measurements

When you use most light microscopes, you can easily see things 100X to 1,000X larger than they really are. Some electron microscopes magnify objects 1,000,000X but about 250,000X is the highest practical magnification. You can quickly get into hundredths, thousandths, millionths, and billionths of an inch. Just as you deal in miles and light years rather than millions and billions of inches when you study long distances, you also deal with different units of length as you get smaller.

A **centimeter*** (cm) is about 1/2 in. (2.54 cm = 1.0 in.). If a centimeter is divided into ten equal parts, each part is a **millimeter*** (MIL uh MEE tur) (mm). A millimeter scale is often shown on

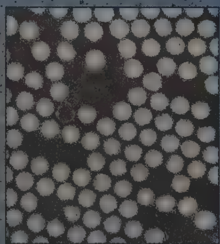


human finger (2.5X)



leaf cells (35X)

crab louse claw (100X)



polio virus (100,000X)

rulers and a single millimeter unit can easily be seen with the unaided eye. Some large microbes can be measured in millimeters.

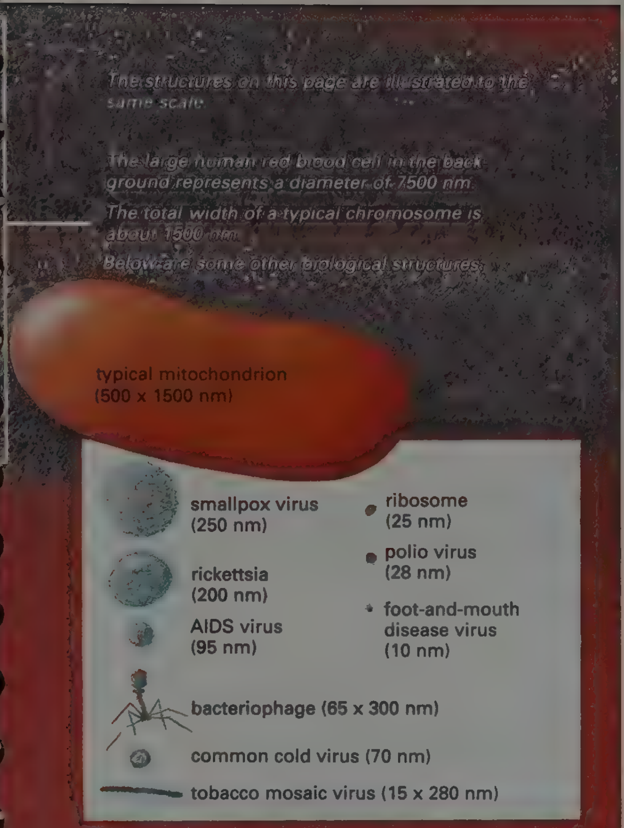
If a millimeter is divided into 1,000 equal parts, each part is a **micrometer*** (my KRAHM ih tur) (µm). Most microbes, like amebas and algae cells, are approximately 100 µm long. To see things of this size, one must magnify the image at least 100X on a light microscope. Many human body cells are about 20 µm and human red blood cells average only 7.5 µm across. To make these structures clearly visible, 400X is necessary. Most medium-sized bacteria are about one micrometer. These require 1,000X on the light microscope to be seen.

If a micrometer is divided into 1,000 equal parts, each part is a **nanometer*** (NAN uh MEE tur) (nm). Some small bacteria are about 100 nm, and the mumps virus is approximately 115 nm.

	m	cm	mm	µm	nm	Å
m	1	0.01	0.001	0.000001	0.000000001	0.0000000001
cm	100	1	0.1	0.0001	0.0000001	0.00000001
mm	1,000	10	1	0.001	0.000001	0.0000001
µm	1,000,000	10,000	1,000	1	0.001	0.0001
nm	1,000,000,000	10,000,000	1,000,000	1,000	1	0.1
Å	10,000,000,000	100,000,000	10,000,000	10,000	10	1

To appreciate the smallness of these measurements, consider the following. If a meter were enlarged to the distance between Spokane, Washington, and Washington, D.C., then

- *a millimeter would be the distance around the Indianapolis 500,*
- *a nanometer would be the thickness of 2 nickels, and*
- *an angstrom would be the thickness of a paper clip.*



This virus appears as a mere dot on the highest powered standard light microscope, but it is easily seen with the electron microscope. The polio virus, one of the smallest viruses, is only about 25 nm. It cannot be seen with a light microscope.

If a nanometer is divided into 10 equal parts, each part is an **angstrom** (Å). If a meter (about 39 in., just longer than 1 yd.) is divided into 10 billion equal parts, each part is an angstrom. Many structures inside the cell are measured in angstroms. The membrane which surrounds cells is usually 75-100 Å thick. Structures larger than 5 Å are theoretically visible with an electron microscope if they can be properly treated. The smallest atom, hydrogen, is about 1/2 Å in diameter.

two sets of lenses, is called a *compound microscope*. Because of the distance necessary between the lenses, early compound microscopes were often over 0.6 m (2 ft.) long.

The best known microscopist is probably Anton van Leeuwenhoek (LAY wun HOOK), a Dutch merchant who had a hobby of lens grinding in the early 1600s. Leeuwenhoek used simple microscopes rather than the cumbersome compound microscopes of his day. Some of Leeuwenhoek's lenses were smaller than a pinhead, and he had to push the lenses almost into his eye in order to see anything.

Leeuwenhoek made over 200 different microscopes, which had various mountings to view many types of specimens. Some of his discoveries include circulation of fluids in the tiny vessels of a living fish's tail, thousands of microbes, blood cells, sperm, and even various human tissue structures. For most of his long life Leeuwenhoek sent his observations of "very many wretched little beasties all cavorting about very nimbly" to the Royal Society of London. Leeuwenhoek, who is called "the Father of Microscopy," never saw an object magnified more than 160 times. Today, even the microscopes commonly used in high schools can magnify 400 times (400 times can also be written 400X in which the "X" means *times larger*).

The compound light microscope

The *compound light microscope* is commonly used in classrooms and laboratories today. It consists of one set of lenses to magnify an object and another set to serve as a telescope to further enlarge the image and permit the observer to look at it from a convenient distance. In a light microscope the two sets of lenses are located in the **objective** and the **ocular*** (AHK yuh lur) or eyepiece. Many microscopes have a *revolving nosepiece* which permits several objectives with different magnifications to be used.

When you look *through* the microscope, you see light that has passed through the specimen on the **stage,** through the objective lens, through the **body tube,** and through the the eyepiece lens. Actually, you are seeing the "shadow" of the

micrometer: micro- (small) + -meter (measure)

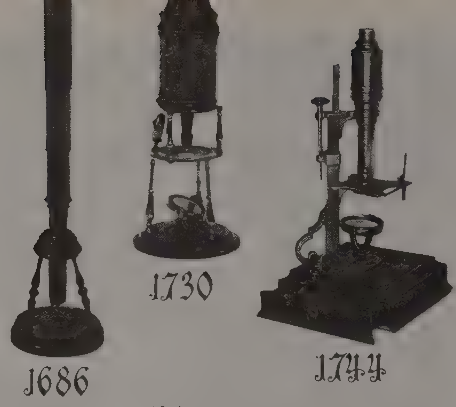
nanometer: nano- (L. NANUS, dwarf) + -meter (measure)

ocular: (L. OCULUS, eye)

A stentor (a very large protozoan) can sometimes be measured in centimeters. You can see one on a preserved slide by just holding it up to the light.

Visual 1C-2 is a diagram of the light microscope which can be labeled with those structures that students need to know. Consider writing these labels on the diagram while discussing them. It is also possible to photocopy this visual and hand it out to students so that they can put their notes regarding the microscope on it.

Visual 1C-3 is a diagram of the light and electron microscopes compared to show similarities and differences.



1C-4 *Old compound microscopes*

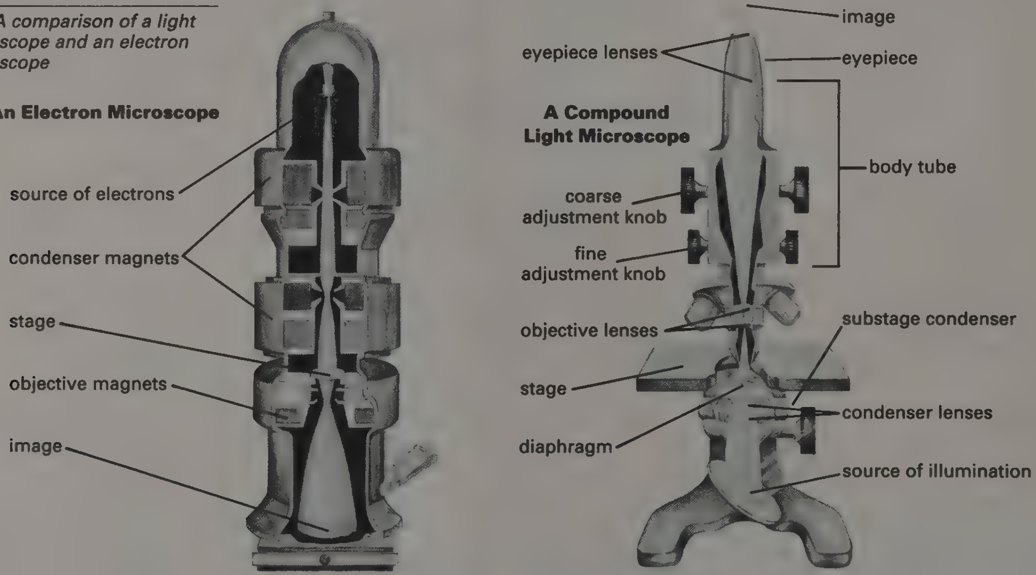
specimen since you observe light that has passed *through* it and not light that is reflected from it. Microscopes are focused by moving the objective lens closer to or farther from the specimen.

Many modern microscopes have two eyepieces. Some of these microscopes (especially higher-powered ones) give the same image to both eyes. Others, however, are *stereoscopic microscopes* that provide two slightly different views of the same object, similar to the images one gets when looking at an object with both eyes. These slightly different views result in depth perception. A number of these stereoscopic microscopes are low-powered and use light reflected from the specimen which is placed relatively far from the objective lens. Microscopes of this nature are frequently used for dissecting small specimens.

The electron microscope

One of the most useful tools for biological investigation developed in the twentieth century is the **electron microscope.** The electron microscope replaces light rays with electrons which are exceptionally small and straight-traveling. Because more electrons than light waves can pass through a given area at a given time, electron microscopes can magnify many times greater than light microscopes. Since electrons are smaller than light waves, electron microscopes have a much greater capacity for resolution.

1C-5 *A comparison of a light microscope and an electron microscope*



Principles of Light Magnification

Normally the **reflection** of light from the surface of an object makes it visible to the eye. If, however, a lens is placed between the object and the eye, the light waves will be bent. The wavy patterns seen through some window glass or the apparent bend in a drinking straw placed in water are results of light waves being bent as they pass through the transparent substances. This bending of light as it passes through a substance is called **refraction.** The refraction of light as it passes through a curved lens either enlarges or shrinks an image.

Refraction causes the pencil to appear bent and enlarged.

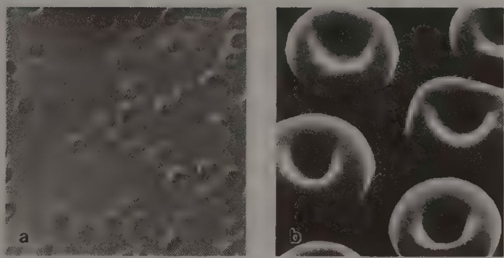
There are limits to magnification. Since only a certain amount of light reflects from or passes through a specific point at one time, no image is visible if these waves are spread too far apart. The ability to distinguish fine detail is called **resolution.** The unaided human eye can distinguish two points 0.1 mm apart, but points closer than that appear as a single point. If two points 0.1 mm apart are magnified 100X, however, they will *appear* 10 mm apart. When an image is magnified, the resolution increases.

There is, however, a limit as to how close two points can be and still appear as two individual points when magnified with a light microscope. In part, the ability of a lens to clearly separate two points depends on the quality of the lens. Due to the size of light waves, points too close together become distorted as they are magnified. Even the highest quality lens, therefore, has resolution limits.

Electrons do not pass through any substance very easily; in fact, the specimen in an electron microscope must be in a vacuum because the electrons would be affected by the air molecules. Specimens viewed on an electron microscope must be sliced extremely thin. They must also be treated with relatively harsh chemicals which do not permit electrons to pass. These electron-dense substances sometimes change or damage the specimen.

A lens does not bend the paths of electrons but does stop almost all of them. So, rather than lenses, electromagnets of various charges and strengths pull or push on the electrons, either condensing or separating them. Although electrons cannot be seen by the human eye, they can affect photographic plates and can be detected by electron-sensitive devices which transfer images of the electrons to a screen like a television tube. *Electron micrographs,** the pictures produced by an electron microscope, have no color but only light and dark areas where electrons passed or did not pass through the stained specimen.

The *scanning electron microscope*, a special kind of electron microscope, is used to obtain



1C-6 *Comparisons of (a) a light micrograph and (b) an electron micrograph of red blood cells*

A scanning electron micrograph of a louse

micrograph: micro- (small) + -graph (Gk. GRAPHEIN, to write)

One can demonstrate reflection with a mirror and refraction with a glass of water. Using Petri dishes and pencils, demonstrate refraction, using the overhead projector. Illustrate resolution by putting two dots on the overhead and then adjusting the focus.

Pictures such as those on pages 69, 71, and 553 (bottom) are taken through light microscopes. A transmission electron microscope produces pictures such as those on pages 73, 76, and 77. A scanning electron microscope produces pictures such as those on pages 553 (top) and 619. All electron micrographs are black and white; color is often added for interest and clarity.

Most microscope slides are stained. Showing students the same structure stained with different stains could be profitable. Some root tip cells are stained with "double stains" in order to see mitosis more clearly. These can also be used to demonstrate staining techniques.

images of the surfaces of structures. After an electron-dense substance is applied to the surface of a specimen, this special electron microscope produces images up to 20,000X.

The electron microscope can magnify from 1,500X to 250,000X. In other words, it starts at the highest magnification possible on a light microscope and can magnify that image about 160X.

Review Questions 1C-2

1. Who is called ''the Father of Microscopy,'' and how did he earn this title?
2. Describe how a lens magnifies an image.
3. Why must you use a thin specimen when viewing with a light microscope?
4. What structures of an electron microscope are comparable to the following requirements for the light microscope: (a) light waves, (b) lenses, (c) viewer's eye, (d) mirror or light source?
5. Give the size relationships between a meter, centimeter, millimeter, micrometer, nanometer, and an angstrom. (Example: 100 cm in a meter)
6. Give an example of something that would easily be measured by using each of the following units: meter, centimeter, millimeter, micrometer, nanometer, and angstrom.

Variables in biological studies

Because God designed life to function in a certain range of environmental conditions, it is difficult to experiment with living things. When a person wants to measure the amounts of oxygen and hydrogen needed to produce a certain amount of water, the experiment can be repeated over and over with the same results. An experiment to determine how much weight a horse can pull, however, would be affected by many variables including type of horse, its age, health, and size. Some of these factors could be controlled by using the same horse for all experiments, but then fatigue and boredom would have to be considered. The results of such an experiment could not be applied to all horses.

Because life is a dynamic condition, experimenting with it is difficult. Limiting the variables is the problem; large experimental groups in oft-repeated experiments are necessary to obtain even a reasonable degree of validity (reliability, workability). This often requires a long period of time, which explains why scientists are still not sure of such things as the effects of certain drugs. It also explains why a new drug or treatment cannot be released by government authorities until after extensive testing. A small number of tests on only certain people may not reveal enough about the drug to indicate its safety or effectiveness.

A student conducting an experiment for a science fair project put hamsters into two groups of five hamsters each. His hypothesis was that hamsters on a diet of seeds and carrots would gain weight and be happy and healthy, while hamsters being fed cake and cookies would lose weight and become sickly. All the seed-and-carrot hamsters remained the same weight and appeared happy and healthy. Most of the cake-and-cookie hamsters also kept the same weight, but two of them gained a considerable amount of weight. All, however, still appeared happy and healthy.

A similar problem in experiments is illustrated by van Helmont's tree experiment (p. 8) and his spontaneous generation of mice experiment. Needham's spontaneous generation of microbes experiment had factors which were not taken into account.

Because the science fair was close at hand, the student began to draw conclusions about cake, cookies, and hamsters. The day of the fair, though, he found two litters of baby hamsters in the cake-and-cookie hamster group along with two considerably slimmer hamsters. His conclusions had been wrong because there was a factor he had failed to take into consideration.

You may smile, but eminent, qualified scientists have made the same type of mistakes over and over again. All the variables involved in a living condition are almost impossible to control; therefore, reliable experimentation on living things is difficult.

The validity of biological studies

From this discussion about some of the tools and techniques biologists use to study life, one thing should be evident: studying life itself is not easy. There are far too many variables to control.

- Errors can be made by the biologist in his observations.
- Errors can result if the specimen is not typical.
- Errors can be made when the techniques used are crude.

To overcome these problems, a scientist testing a living organism must usually repeat his work many times with a high percentage of similar results before considering a conclusion valid.

Answers–Review Questions 1C-2

1. Anton van Leeuwenhoek. Using simple microscopes, he observed microbes, blood cells, sperm, various human tissue structures, and circulation in tiny vessels of living fishes' tails (magnified up to 160X).
2. As light passes through a lens, the rays are bent, or refracted. Refraction of light passing through the curved surface of the lens produces an enlarged image.
3. It must be thin to allow light to pass through.
4. **(a)** light waves–electron beams; **(b)** lenses–electromagnets, various charges; **(c)** viewer's eye–photographic plates, images on a screen; **(d)** mirror or light source–electron source

*5. 1 meter = 100 cm = 1000 mm = 1.0×10^9 nm = 1.0×10^{10} Å

*6. meter–height of person or tree; centimeter–width of fingernails, length of pencil; millimeter–large microbes, thickness of a fingernail, width of pencil; micrometer–red blood cells, other cells; nanometer–small bacteria, viruses; angstrom–cellular structures, cellular membranes, atoms

*From a box.

1C-1

FACETS OF BIOLOGY

Biological Research Techniques

Today's scientists have many sophisticated tools which allow them to observe, often indirectly, many things which would have been impossible to know about in the past. Some of the techniques described below are used in the medical profession to aid in making diagnoses. Others are used primarily in researching the structure and function of microscopic living things.

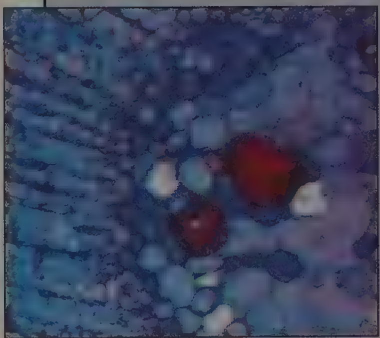
❑ *Staining* Although some cellular components are specific colors, most are clear. Scientists often use stains to make various substances visible. Because stains only color specific chemicals, the presence of those chemicals can be detected by the use of those stains. Some stains can be used on living cells, but most stains must be used on dead materials.

❑ *X-rays* X-rays easily pass through thin materials, but pass less slowly through dense materials. By exposing a structure to X-rays and then catching the rays that pass through the structure on photographic film, scientists can learn about the internal structures without cutting into the structure. Since many structures in living things are similar in density, scientists often must use substances that make the structures more dense. To view the structures of the digestive system, people are often asked to drink an X-ray dense substance (a substance which blocks X-rays). The X-ray pictures then show the digestive system's structures.

❑ *Computerized Axial Tomography Scan (CAT or CT scan)* X-rays are passed through a single area from different angles and are picked up by a detector. The information is fed into a computer, compared, and made into a picture. A CAT scan machine is about 100 times more sensitive than a conventional X-ray machine and does not use X-ray dense material to identify structures.

The physician prepares a patient to enter the CAT scan machine.

❑ *Ultrasonography** (UHL truh suh NAWG ruf fee) Ultrasound is much like the sonar used by ships. A device which releases sound and then picks up the echos of that sound that bounce off internal structures is moved slowly on the surface of the body near the structures. The resulting data is fed into a computer which produces a picture based on the speed and quality of the echo. The pictures are not as accurate or precise as CAT scans or X-rays, but are quite useful in observing unborn children, who can be harmed by X-rays. Ultrasound pictures are useful also in studying the heart, which is often



A micrograph of plant stems that are stained to show different tissues (left). An X-ray reveals a broken bone in a person's foot (right).

ultrasonography: ultra- (L. ULTRA, beyond) + -sono- (SONORUS, sound) + -graphy (to write)

This Facet should be covered by advanced classes or advanced students. An average class can deal with the material, but it may require class time better spent on other topics. This Facet presents a survey of different methods scientists can use to learn about living things. Consider having the students be accountable for some of the techniques, but not all of them. Have them read the Facet so that the better students can understand the material, but in class, cover only the techniques the majority of the students can comprehend.

The entire Facet should be covered in detail by advanced students in advanced classes or students who plan to go on with scientific studies. In advanced classes set up various demonstrations of these techniques, or make arrangements with hospitals or other facilities to have them demonstrated. The various techniques can be assigned as research topics to advanced students who will then give reports to the class. Students should be able to find examples of the various techniques and possibly even demonstrate them.

There are no terms in the Facet which are listed at the end of the chapter; it is suggested that the students be responsible for *staining, X-rays, CAT scan, ultrasonography, cellular fractionation, autoradiography, chromatography,* and *endoscopy,* or a selection of terms from this list.

X-rays can be used to get moving pictures with a machine called a fluoroscope. A cardiac catheterization involves inserting a tube (catheter) into the heart through blood vessels. The tube is then used to release X-ray dense substances into the blood in or near the heart, and X-rays are taken (usually with a fluoroscope) to observe the flow of blood through the heart.

autoradiography: auto- (Gk. AUTO, self) + -radio- (L. RADIARE, to emit beams) + -graphy (to write)

chromatography: chroma- (Gk. KHROMA, color) + -graphy (to write)

endoscopy: endo-, en-, em- (Gk. ENDON, within) + -scopy (to view)

Sooner or later in almost every class, some student will ask something like this: "If this stuff is so small that we can't really see it, how do scientists know how it works and everything?" Often this is asked in order to get the teacher to say that scientists do not really know, and thus make the students' not learning the material justifiable. Other times it is a sincere question about how scientists figure things out. This Facet presents a number of answers to that question.

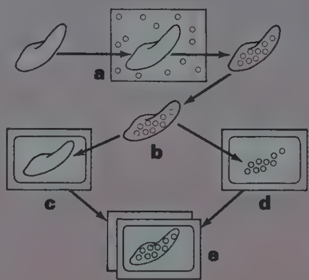
A well-known endoscopic technique is a colonoscopy in which a colonoscope is used to view the colon. Gastroscopes go through the mouth and are used to observe the stomach and first part of the small intestine. They are helpful in looking for ulcers.

Ultrasound being used (inset) to generate this picture of the unborn child

difficult to observe with X-rays because heart muscle is soft tissue.

❑ *Cellular fractionation* Cellular fractionation (FRAK shuh NAY shun) is used to remove structures from inside a cell in sufficient quantity to be analyzed chemically. After a cell has been physically broken and placed in a solution in a tube, it can be put in a *centrifuge* (SEHN truh FEWJ). The centrifuge spins the material at extremely high speeds which causes dense materials to settle to the bottom of the tube and forces lighter materials to the top. In between are layers of cellular pieces of various densities. By taking a layer of material from the centrifuged tube and repeating the process several times, an almost pure collection of structures of a certain density can be obtained and then chemically analyzed. This process permits scientists to determine what chemicals comprise cellular structures.

❑ *Autoradiography* A technique used to study the chemical activity of a structure is autoradiography* (AW toh RAY dee AWG ruh fee). A chemical made with a radioactive element is supplied to a living cell. Since radioactivity affects the photographic plates used in electron microscopes, the presence of this chemical can be pinpointed. For example, if radio-active hydrogen in the form of water (called deuterium) is supplied to a cell, a series of photographs taken through an electron microscope can reveal how fast the water enters the cell and into what cellular structures the water goes.



A representation of autoradiography: (a) Material containing a radioisotope (red dots) is supplied to a cell. The cell absorbs and uses the radioisotope. (b) The cell is then killed, (c) photographed, and (d) exposed to other photographic film which is affected by the radioisotope (black dots). (e) The two photographs are combined to locate the radioisotope.

❑ *Chromatography* Scientists often use chromatography* (CROH muh TAWG ruh fee) to separate substances in a solution. An absorbing material (often a strip of special paper) is placed in the solution, and the various materials go up, like water being picked up by a paper towel. The various materials in the solution are different weights and thus go to different heights on the absorbing material. Bands containing different substances from the solution are formed on the absorbing material.

Paper chromatography

❑ *Endoscopy* Endoscopy * (en DAH skuh pee) is a name for using a hollow tube or a fiber optic cable to look inside a structure. Often the tube will have devices in it which permit the scientist to supply light to the dark area, remove specimens, perform surgery, or pump air into the structure so that it can be seen more clearly. Different endoscopes are designed for looking at various structures. Some endoscopes are inserted through natural body openings such as the mouth or nose; others enter through incisions made by a physician or scientist.

Review questions on next page.

Answers–Review Questions 1C-3

1. The description does not explain how or why the structures function.
2. Life is a condition which has many variables to its existence. Taking all the variables into account and controlling them is very difficult.
3. **(1)** Observational errors; **(2)** atypical specimens; **(3)** crude techniques. Scientists try to overcome these problems by repeating their work several times to get a high percentage of similar results before they consider a conclusion valid.
4. A model is a guess at how something operates. It is an explanation based on scientific observations. In order to use scientific information, scientists often must construct models to aid their understanding.

Answers–Facet 1C-1

1. **(1)** Staining helps scientists see substances that are not easily visible. **(2)** X-rays permit scientists to "see" dense materials inside a structure. **(3)** CAT scans use X-rays from various positions to produce images that reveal areas of different densities. **(4)** Ultrasonography uses sound and echoes to produce images that reveal areas of different densities. **(5)** Endoscopy uses

The conclusion must also agree with other scientific information about the topic before it can be considered valid. A scientist performing electron microscope observations may conclude that a certain molecule is box-shaped. Another scientist performing experiments on the chemical make-up of the same molecule may conclude that it is ball-shaped. There are several possible explanations for these contrasting results.

- Possibly the molecule can change its shape as it is prepared for electron microscope viewing or as it is analyzed chemically.
- Possibly one or both scientists are wrong in their observations or conclusions.
- Possibly the molecule is both box- and ball-shaped.

In any case, further study is necessary.

Models

Earlier it was noted that science cannot *explain* things. Science only *describes*. This is true because of the nature of science. However, one often finds *explanations* in scientific materials. Descriptions of *how* things operate is a major part in the study of biology or any other science. An explanation of how something works is called a **model.**

Scientists devise models to explain the data they have obtained. A series of different experiments can tell much about a process. Putting all the experimental information together so that it "works" logically can produce a model. Further experimentation often reveals more information. If the results of these additional experiments agree with the model, the model is assumed to be more valid. If these results do not support the model, then either that data is in error, or the model must be greatly changed or discarded.

Despite the fact that models are often changed, they are the only method man has to describe *how* something functions. Knowing how a process operates is often crucial for man to effectively use the process he is ordained of God to use. As you study various models in this book, however, recall that any explanation is merely *man's guess* at how *God ordained* something to operate.

Biological Terms

biology	organic	*The Study of Life*	objective	resolution
The Attributes of Life	protoplasm	microscope	ocular	model
living condition	inorganic	centimeter (cm)	stage	
internal movement	irritability	millimeter (mm)	body tube	
assimilation	food	micrometer (μm)	electron microscope	
reproduction	life	nanometer (nm)	reflection	
variation		angstrom (Å)	refraction	

Review Questions 1C-3

1. Why is a description of the structures found in a living organism not adequate to describe life?
2. Why is studying living organisms difficult?
3. List several problems that can affect the validity of experiments with living things.
4. What is a scientific model, and why do scientists construct them?

Facet 1C-1: Biological Research Techniques, pages 39-40

1. List and describe five techniques used by scientists to enhance their ability to observe various structures.
2. List and describe four techniques used by scientists to determine the chemical make-up of a structure.

Thought Questions

1. Based on an analysis of the attributes of living things, could a robot with a highly sophisticated computer attached to it be considered alive? Why or why not?
2. Why are models important in science? Why can no model be accepted as a completely valid explanation of a phenomenon?

Devising a model is an unscientific scientific activity. The scientific model concept is an excellent topic to use as a review of the main points presented in this chapter. Rather than merely repeating the main points in a series of questions, consider reviewing the chapter as the concept of models is presented.

Science deals with observations. Making models deals with speculations about observations. The more accurate the observations are, the more likely it is that the model will be accurate; but speculations are always, by definition, unscientific. Models, however, are necessary if science (man's observations) is going to be at all useful. Pure science is of little value until the observations are used to do something (applied science). Most often this involves organizing the observations of pure science into a model.

Model building is not science because it goes beyond the limits of science, nor is it wrong or wicked. Model building can be very valuable in making science (true science–observations) useful. What is wrong is to try to make model building a way to "establish truth." This is a good place to review the place of science in regard to Truth. What science actually is can also be reviewed here.

The process of photosynthesis as described in Chapter 4, for example, is a model. Man can experiment with such questions as "Do plants need light to make sugar? What kind of light do plants need to make sugar? Do plants need chlorophyll to make sugar?" When man assembles the data to show *how* plants make sugar, he has left pure science and has begun dealing with models.

tubes or fiber optics to look into various small places.

2. **(1)** Cell fractionation is the process which removes from the cell the structures to be analyzed. The structures are placed in solution, centrifuged, and analyzed. **(2)** Staining techniques are a means of determining the chemical composition of certain cell parts by applying stains which cause specific reactions in certain chemicals. **(3)** Autoradiography introduces radioactive elements into living cells; their presence and function in cell processes can be observed in photographs taken through an electron microscope. **(4)** Chromatography permits the separation of various substances based on their different weights or shapes.

Answers–Thought Questions

1. No. It cannot reproduce, grow, or die (because it has never lived); it does not come from preexisting life and is not composed of cells.
2. Models enable men to describe, and therefore communicate, theories and concepts. All models are based on incomplete data; man's ability to observe is not completely accurate, so the model cannot possibly take all the variables into consideration.

chemistry: chem-, chemi-, or chemo- (Gk. KHEMEIA, alchemy, *hence,* chemistry or chemicals)

Time Frame
2A (with Facet): 2-3 periods
2B (with Facet): 2-3 periods

Lab Activities
2A–*Osmosis and Digestion* involves observations of osmosis and the action of enzymes. Schedule this lab after enzymes are discussed; it is best done as a demonstration. It will take 5-10 minutes to set up the experiment. Observations should be made every 10 minutes for the rest of the period. Other instruction can take place between observations.

TWO

THE CHEMISTRY OF LIFE

2A–Basic Chemistry

Biology was once almost entirely *natural history;* that is, learning to recognize organisms and discovering where they lived constituted most of the study of biology. Then came *descriptive biology.* Scientists, armed with hand lenses and microscopes, described in minute detail the structures of everything that grew, crept, or flew, as well as a few things that were not even alive.

Today, however, biology is mostly the study of *how* structures function. Whether in a test tube or in a living cell, the same substances behave according to God-ordained rules. This is why one must first understand **chemistry*** (the study of those substances and the rules that govern their behavior) in order to understand biology.

Matter

It is not always easy to distinguish the two basic components of the physical universe, matter and energy, because they exist and work together. For the sake of simplicity, though, this study of basic chemistry will consider each of them separately.

2–The Chemistry of Life

Understanding certain chemical principles is basic to understanding biology. Although much of Chapter 2A is review for most students, reviewing this material will aid their understanding of Chapter 2B and other sections of the text.

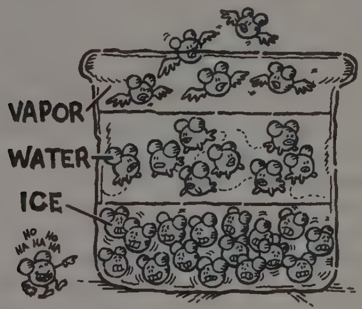
The goal in a biology course is to have enough understanding of atomic structure, bonding, energy relationships, and similar chemistry-related processes to make biological processes comprehensible. Present this material quickly as a survey or review. The content of this chapter should be learned in courses such as physical science, basic science, or chemistry.

The material in Chapter 2B will be new to most students and must be presented carefully. Understanding the content of Chapter 2B will help students better evaluate current health-related advertisements and articles. A basic knowledge is helpful not only for study but also for other areas of life.

The abstract nature of biochemistry makes it difficult for some students and teachers. Many teachers want to postpone this study until the end of the course, and teach it only if time permits. The main criterion for including a topic should be the value it holds for the student now and in the future. Since the advantages of an understanding of basic biochemistry are not always obvious to the student during preliminary study, the teacher should take every opportunity to stress the usefulness as the chapter is studied. Assure students that the value of biochemistry becomes clearer as they continue studying biology.

Notice the shaded shapes representing water (introduced on p. 43, constructed on p. 45), carbohydrates (pp. 46, 61-62), amino acids (p. 64), fatty acids and glycerol (pp. 63-64), and DNA and RNA (p. 67) in this section. These shapes will be used throughout the text to serve as teaching

The simple definition of matter (although scientists are modifying it as they learn more about the physical universe) will suffice here: **matter** is anything which occupies space and has mass. Normally there are three *states of matter:* solid, liquid, and gas. Actually, these states of matter are the result of varying amounts of energy possessed by that matter. If heat, a form of energy, is added to solid water (ice), the water will enter the liquid state; and if more heat energy is added to the water, it becomes a vapor, the gaseous state.



Elements and atoms

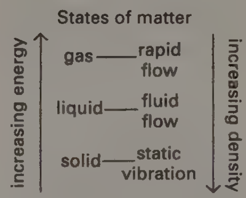
Matter is composed of over 100 known elements. Occasionally, scientists synthesize another element in the laboratory, but usually these elements are highly unstable. **Elements** are those substances that cannot be broken down into simpler substances by ordinary chemical reactions.

According to the atomic theory, cutting a piece of pure gold (one of the elements) in half, and then in half again, and again, and again, in time would yield a piece that could not be cut again and still be gold. That piece would be an **atom,** the smallest unit of an element that is still that element. Although nuclear reactions can break atoms apart, the products of these reactions are no longer the original element. Scientists now isolate atoms and detect their presence by using specialized electron microscopes, but no one has yet clearly seen individual atoms. Our notions of their existence and what they are like are only workable theories.

The *periodic table of the elements* is an arrangement of the elements according to the structure of their atoms. This table displays the *element symbols* (usually the first letter or letters of the chemical names in Latin or English). The common elements found in living organisms are listed along with their symbols in table 2A-1. The first four elements listed are essential to all life in large amounts. The next seven elements are essential to all life in smaller amounts. The rest of the elements in the table are *trace elements,* which are essential to some organisms only in tiny amounts.

An atom is not solid (like a marble). One model pictures an atom somewhat like our solar system: a central part and outer moving parts with much space in between. In the center of the atom, clustered into a group called the *nucleus,* are **protons,** the positively charged particles, and **neutrons,** which have no charge. In a constant state of circling motion within levels or shells around the nucleus are the **electrons***–particles with negative charges. There are other subatomic particles that need not be discussed here.

electron: (Gk. ELEKTRON; amber, *which when rubbed produces electricity; hence,* electricity)



2A-1 The Elements of Life

Symbol	Element	Abundance in Human Body (% Weight)
O	Oxygen	65
C	Carbon	18
H	Hydrogen	10
N	Nitrogen	3
Ca	Calcium	2 (O–Ca together: 98%)
P	Phosphorus	0.5-1.0 each
K	Potassium	
S	Sulfur	0.1-0.5 each
Cl	Chlorine	
Na	Sodium	
Mg	Magnesium	
Cu	Copper	less than 0.1 each
Fl	Fluorine	
Fe	Iron	
I	Iodine	
Zn	Zinc	

☐ Essential ☐ Trace

Elements commonly found in organisms are frequently referred to in this book. Students should learn the symbols for the essential elements.

aids. They are used each time the compounds are illustrated. Other compounds (e.g., ATP, ADP, chlorophyll, and hydrogen acceptors) are assigned shapes in later chapters.

2A–Basic Chemistry

Notes–Chapter 2A

Chapter 2A is a great place for a dozen fun demonstrations. The properties of various substances and the chemical reactions spoken of in this chapter are easily demonstrated with minor equipment. This would be a good time to set some "scientific inquiry" classroom procedures to develop skills that will be useful later.

Objectives–Chapter 2A

- ❑ Define *matter* and *energy.*
- ❑ Describe an atom.
- ❑ List the symbols of elements most commonly found in organisms.
- ❑ Describe bonding.
- ❑ Define *compounds.*
- ❑ Differentiate between a chemical change and a physical change.
- *❑ Discuss acids and bases.
- ❑ List and describe two types of energy.
- *❑ Differentiate between solution, suspension, and colloid.
- ❑ Describe diffusion and osmosis.
- ❑ Define *catalyst.*

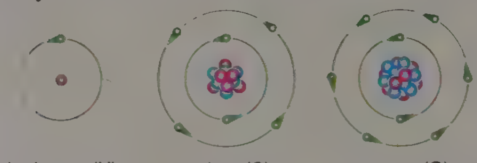
*From a Facet.

This should be a brief survey of the basic principles of chemistry. Limit the time spent on this material, but stress those concepts that will be needed for later study in the text. The chapter is written with this emphasis; so some material obvious to a trained science teacher has been omitted.

The make-up of the nucleus determines the kind of atom. The electrons affect chemical properties.

The nucleus of the atom is relatively distant from the electron shells. If a single oxygen atom were the size of a football field, the nucleus would be the size of a tennis ball in the center, and the electrons would be the size of pinheads circling the field at the distance of the goal posts. Most of matter, then, is empty space between the nucleus and the electrons of atoms. The matter which makes this book is quite solid, even though it is made of atoms which are mostly space. Strong forces hold the atoms of this book together so that they form a solid substance.

The arrangement of electrons in the shells is known as the *electron configuration.*



Because of its biological importance, consider "diagramming" carbon as an example atom in class.

What forces hold electrons and protons together as atoms, and what forces bind atoms together? Scientists believe that the opposing charges of the electrons (−) and the protons (+) cause them to stay together as an atom. To understand what binds one atom to another, we need to know more about the atom's make-up.

Atoms of different elements differ in their number of subatomic particles (electrons, protons, and neutrons). In a single atom, however, the number of electrons is always the same as the number of protons. If there is 1 proton in the nucleus and 1 electron in its shell, the atom is hydrogen. The atom with 8 protons (with the proper number of neutrons) in the nucleus and 8 electrons is oxygen. The *atomic number* in the periodic table indicates the number of protons in the atoms of that element.

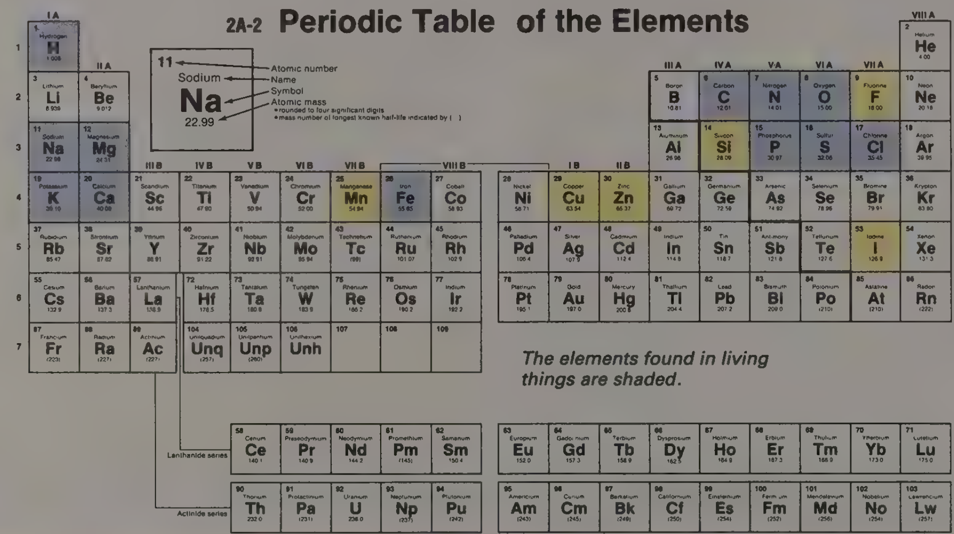
If the number of electrons and protons in an atom decreases or increases, the atom becomes a different element. Normally, the number of protons in an atom does not change except in nuclear reactions, as in atomic bomb explosions, nuclear power reactors, or stars.

Chemical bonding: ionic

This is called the *octet rule*. When an octet (8 in the outer shell) is achieved, the compound formed is stable.

Most atoms are unstable and will normally bond with other atoms to become more stable. An atom is stable when its outermost electron shell is full. The innermost electron shell, which is the first to be filled, can contain only 2 electrons. The second shell can hold 8 electrons. The next shell has the potential to hold 18 electrons but acts as if it were full when it has 8. The shells farther out hold

The elements that make up the bulk of living organisms are nonmetals; however, many metals are essential to some structures (e.g., calcium in bones).



The elements found in living things are shaded.

Facet–Chapter 2A

The two Facets in this section are more important to the study of biology than some of the points made in the chapter. These topics are (1) acids and bases and (2) solutions, suspensions, and colloids. They are often studied only in chemistry or physical science courses, but they are essential to a good understanding of biology. Cover these two Facets even if it is possible, by virtue of the students' background, to omit the rest of the chapter.

Visuals 2A-1 and 2

❏ *Visual 2A-1* is a diagram of an "empty atom." Use it, if needed, to make various atoms on the overhead projector. Cut out small circles of one color of cellophane to serve as electrons, circles of another color to serve as protons, and circles of a third color to serve as neutrons. (A hole punch works well to make many circles quickly. If cellophane or another colored, transparent material is not available, cut paper dots for protons, squares for neutrons, and stars for electrons.)

After establishing the dots/shapes at the bottom of the diagram, place one proton in

larger numbers, but all behave as full when they have 8.

Those atoms with full shells are quite stable (the noble gases: helium, neon, argon, and so forth). Other atoms, especially if their outermost shells lack 1 or 2 electrons or if they have only 1 or 2 electrons, seem quite willing to give, get, or share electrons in order to have a full outermost shell. Atoms that give, get, or share electrons to become more stable are *chemically active*.

For example, an atom of chlorine, a chemically active nonmetal, has 17 electrons: 2 in the first shell, 8 in the second shell, and 7 in the third shell. If it gets 1 more electron, it will have a full outermost shell. Sodium, a chemically active metal, is the opposite. It has 11 electrons: 2 in the first shell, 8 in the second, and 1 in the third. If it gives its outermost electron, it will have a full second shell. When these 2 elements meet, sodium gives its outermost electron to chlorine, which takes it readily and fills its outermost shell. When these 2 elements meet, they combine to form a *compound*–table salt. Salt is more chemically stable than the 2 elements which form it.

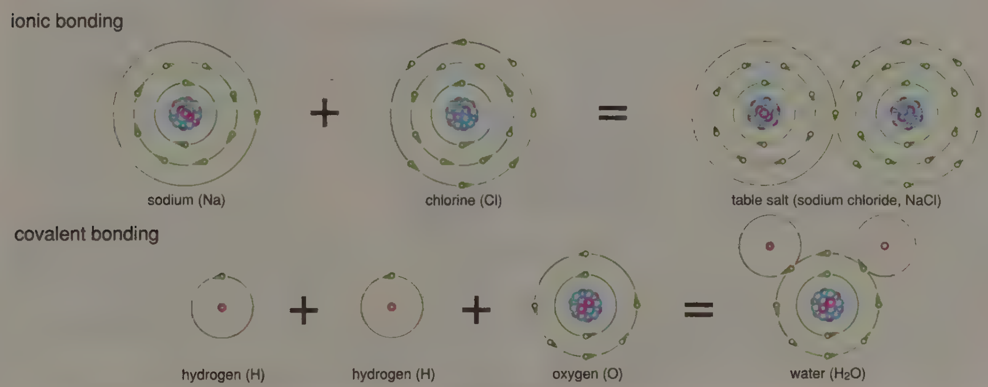
Since one atom gives and the other gets an electron, the atoms of sodium and chlorine in salt each have *unequal* numbers of electrons and protons. An atom with a charge (not having an equal number of protons and electrons) is called an **ion*** (EYE un). Since the sodium in salt is missing an electron, it is a *positively charged ion*. In other words, it has more positive charges (protons) than it has negative charges (electrons). The chloride ion, however, is a *negatively charged ion*. It has more electrons than protons. The giving and taking of electrons, forming ions, is called **ionic** (eye AHN ik) **bonding.** Since all cells are surrounded by and contain ions, the study of ions and ionic bonding is significant to biological studies.

Chemical bonding: covalent

Another type of chemical bonding involves the *sharing* of electrons. The forming of a water molecule is a good example. Hydrogen has only 1 electron and requires another to fill its first shell. Oxygen has 8 electrons: 2 in its first shell and 6 in its second shell. Two more electrons would complete the second shell of the oxygen atom. One oxygen atom will therefore combine with 2 hydrogen atoms. The oxygen shares 1 electron from its second shell with each of the 2 hydrogen atoms so that each hydrogen atom has a filled shell. The 2 hydrogen atoms share their electrons with the oxygen so that the oxygen has a filled outer shell.

Two hydrogen atoms bonded to an oxygen atom form a water molecule. These atoms *share* the electrons involved in this bond. This sharing of electrons is called **covalent** (koh VAY lunt) **bonding** and is a strong chemical bond. Covalent bonds do not separate easily.

2A-3 *Two types of chemical bonding*



ion: (Gk. ION, something that goes)

The transfer of an electron has occurred, forming a positive sodium ion (Na^+) and a negative chloride ion (Cl^-).

The metals with only 1 or 2 electrons in their outermost (valence) shells lose those electrons in ionic bonding to become positive ions. The nonmetals that lack only a few electrons in their valence shells will gain electrons in ionic bonding and become negative ions.

The attraction between ions with opposite charges is called *electrostatic attraction*. The principle that "opposites attract" is the reason that ionic compounds usually consist of a positive metal ion and a negative nonmetal ion.

Note that a pair of electrons is shared, one from oxygen and one from hydrogen.

This illustrates molecules well. Ask students, "Of what does a water molecule consist?" They should reply that water is made up of two H atoms and one O atom covalently bonded into a single unit, or molecule. Consider diagramming O_2 and N_2, which are diatomic molecules.

Bonding occurs when atoms gain, lose, or share their electrons.

the nucleus area and ask students what is needed to make this a complete atom. *(an electron)* Put the electron in the nucleus. Ask if this is correct. *(No; put it in the first shell.)* Ask what atom this would be. *(hydrogen)* Why? *(because it has only one proton and one electron)* Ask where a neutron should be placed. *(in the nucleus)* Ask if this is now a different element. *(No.)* Well it must be something different, since it has a different number of particles making it up. What is it? *(an isotope)* Add another proton. Ask what has to be done now. *(Add another electron.)* Place the electron in the second shell. Ask if this is correct. *(No; the electron should be in the first shell.)*

In a similar manner, make several other atoms. O, C, Na, and Cl are recommended.

Make ions of Na and Cl.

❑ *Visual 2A-2* uses the same structure of atoms used in Visual 2A-1. Add color with visual marker pens to match the electrons, protons, and neutrons used, or draw over the dots with the shapes used. These smaller atoms are designed to show chemical bonding–the making of compounds. For example, take the Na atom and the Cl atom, place them close together, and "overlap" the shared electrons. This represents a compound. Then separate the atoms and use hand-drawn arrows to make ions.

Do the same for water. (If necessary, make multiple copies of these pages in order to have enough atoms for different examples.)

Make some carbon compounds (e.g., CH_4, CO_2). Make diatomic molecules of nitrogen (N_2) and oxygen (O_2).

Carbon provides a good example of the contrast between ionic and covalent bonding. Carbon, the basic element of life, has 6 electrons, 2 in its first shell and 4 in its outermost shell. It can either gain or lose 4 electrons, but it usually does neither. Carbon commonly shares 4 electrons with another atom or atoms, forming a covalent bond; therefore, most study of biology is concerned with covalent bonding. As an example in class, diagram bonds between a C atom and 4 H atoms (methane, or marsh gas, CH_4) and between a C and two O atoms (CO_2).

Most of the human body is made up of covalently bonded molecules, but many body fluids contain dissolved ions (ionic compounds), such as salt.

Compound describes both molecules and ionic substances.

Empirical formulas express the simplest ratio between the elements in a compound. For salt, NaCl (1:1), the molecular and empirical formulas are the same. For glucose, $C_6H_{12}O_6$ (1:2:1), the empirical formula is CH_2O.

Ask how many methane molecules could be made from 50 C atoms and unlimited H atoms. *(50)* How many from 50 H atoms and unlimited C atoms? *(12, with 2 H atoms left over)*

Some examples of biological chemical changes include digestion (the chemical breakdown of food), blood clotting (the synthesis of fibrin protein), photosynthesis (the formation of glucose), and respiration (the release of energy from the breakdown of organic molecules).

Not all chemical bonds are ionic or covalent. Many other bonds are somewhere between the two and often form substances which behave like both *ionic compounds* and *covalent compounds*. Those which form ions easily are ionic, but some ionic compounds do not form ions easily. Likewise, all covalent bonds are not equally strong.

Compounds

In the examples given above–water and salt–different elements combined to form different substances called **compounds.** Sodium is a highly reactive metal which in its pure state reacts violently with water producing flammable hydrogen. Chlorine is a very poisonous gas which, when dissolved in water, is used to kill bacteria in swimming pools. Separately, sodium and chlorine are harmful to living things. But bonded together, they form a crystal that is essential to most living organisms.

Hydrogen is a highly combustible gas, and oxygen is a gas necessary for combustion. In compound form, however, they become water, which is used for putting out fires!

Compounds may be made of only a few atoms, as the ones described above, or they may be made up of many atoms. **Molecular formulas** express clearly the number and type of atoms in a compound. The empirical formula for sodium chloride is NaCl. This shows that 1 molecule of table salt contains 1 atom of sodium (Na) and 1 atom of chlorine (Cl). H_2O indicates that there are 2 atoms of hydrogen and 1 of oxygen. $C_6H_{12}O_6$ is the molecular formula for the simple sugar glucose. There are 24 atoms represented in this formula: 6 carbons, 12 hydrogens, and 6 oxygens.

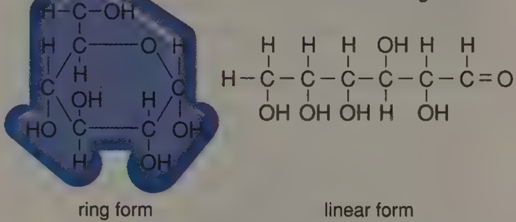
A **structural formula** is often more important in the study of a compound and its reactions with other compounds than an empirical formula. Note in figure 2A-4 the structural formulas for glucose. In a structural formula scientists see where a molecule could bond to another molecule. Notice that there are two different structures that a molecule of glucose can take. Galactose is another simple sugar which has the same molecular formula as glucose because it has the same number and kinds of atoms. In galactose those atoms are bonded together in a different configuration. Its structural formula, therefore, is different. Because of its different structure, galactose has properties slightly different from the properties of glucose.

Molecules

When atoms bond, a molecule is formed. A **molecule** is the smallest unit of a substance that is still that substance in a natural state. Most molecules are compounds such as water, carbon dioxide, sugar, fat, and propane. A carbon atom bonds with 2 oxygen atoms, for example, to form a carbon dioxide molecule (CO_2).

Some molecules, however, contain atoms of only a single element. The oxygen you breathe is not in the form of single oxygen atoms. Atmospheric oxygen is 2 oxygen atoms bonded together forming a molecule of oxygen (O_2). Similarly, other gases, such as nitrogen, hydrogen, and chlorine, combine with themselves to form molecules.

2A-4 *Two structural formulas of glucose*



Chemical changes and physical changes

When atoms or compounds bond together (react chemically), there is a **chemical change.** A chemical change takes place when the atoms of a substance bond with different atoms or compounds. The following are characteristics of all chemical changes:

- Chemical changes take place in definite proportions. Ten hydrogen atoms can make only 5 water molecules, no matter how many oxygen molecules are present.
- New compounds are formed, and/or there is a release of elements.
- Energy is involved.

2A-1

Facets of Biology

Acids, Bases, and Buffers

Most substances, when dissolved in water are either an acid or a base. Most chemical reactions, especially those that take place in living things, are affected by whether they are taking place in an acid or a base and by how strong the acid or base is.

Acids and bases are really opposites which, when they get together, do not fight, but destroy each other. An **acid** is a compound which releases *hydrogen ions* (H^+) when dissolved in water. A **base** is a compound which releases *hydroxyl ions* (OH^-) when it is dissolved in water.

When an acid and base are put together they **neutralize** each other, forming a salt and water. For example, sodium hydroxide and hydrochloric acid will combine to form sodium chloride (table salt) and water.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

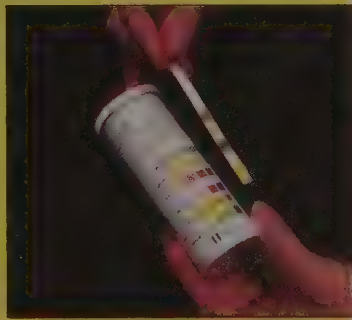
The *acidity* (amount of hydrogen ions) or *alkalinity* (amount of hydroxyl ions) of a solution is usually expressed in terms of a number called **pH** (which stands for "potential of hydrogen"). For biologists, the useful pH scale goes from 1 (very acidic) to 14 (very alkaline). A pH reading of 7 is neutral, meaning the solution has no excess H^+ or OH^- ions.

Living things and pH

The pH surrounding living things is crucial. If you breathe an acid dissolved in the water of the air, you will gag. If the acid is strong enough or you breathe it long enough, you could harm your lungs. pH is especially critical for aquatic organisms. Some fish that normally live in water with a pH of 6.5 will begin to show signs of distress when placed in water with a pH of 6.0, and if placed in water with a pH of 5, they die.

The internal pH of living things is also important. The human stomach enzymes work best if the pH of the stomach is between 1.6 to 2.4. Sometimes a person's stomach may secrete too much acid for too long causing "an acid stomach." If the acid is neutralized by destroying the walls of the digestive system the person has a burning sensation (often called "heartburn" even though it has nothing to do with the heart). One method of dealing with an acid stomach is to eat basic foods (milk, crackers, bread) or to take medicines that contain bases (sometimes called antacids) to neutralize the "excess stomach acid" forming salts and water.

In many living systems there are buffers which keep the pH within a tolerable range. A **buffer** is a substance that will combine with H^+ if it is in abundance or with OH^- if it is in abundance.



A test strip has indicators to determine the presence of various substances in urine. One of the indicators shows the pH.

Your blood, for example, maintains a pH between 7.35 to 7.45 using buffers. If an acidic substance enters your blood the buffers will quickly pick up the excess H^+ ions. The reverse would happen if an alkaline substance gets into your blood.

There are, of course, limits. If someone gets too much of an acid in his blood the buffers may not be able to handle all the ions. His blood pH would go down, and he would end up in a coma; if it goes too far, he would die. The brain cells tolerate only small pH fluctuations beyond the normal range.

Demonstration: Add dilute HCl to dilute NaOH. This forms $NaCl + H_2O$; the water will be salty. Do not taste it!

This Facet presents the definitions of *acid* and *base;* and shows that they neutralize each other and can be buffered. It also teaches that pH is the measurement of acidity and alkalinity and that pH affects living things. The material presented in this Facet is crucial to future chapters. It is suggested that the students read the Facet and that the teacher cover the material in a class lecture.

The terms **acid, base, neutralize, pH, buffer,** and **acid rain** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Possible demonstration: Add baking soda to dilute HCl with phenolphthalein to illustrate buffer reactions. CO_2 gas is released, and the color of the indicator turns pink as the solution becomes basic.

Ask students if the changes described here are chemical or physical changes. Acid/base neutralization is a chemical change.

A person may eat spicy food which will cause his stomach to secrete too much acid; he will rarely eat too much highly acidic food. Acidic foods are rarely near the pH of the normal stomach. Occasionally a person's diet may lack enough alkaline foods to neutralize his stomach acids, requiring a change of antacids or diets.

Strongly acidic–below 2.5; moderately acidic–2.5 to 4.5; weakly acidic–4.5 to 6.5; neutral–6.5 to 7.5; weakly basic–7.5 to 9.5; moderately basic–9.5 to 11.5; strongly basic–above 11.5.

Use pH paper to illustrate the pH of saliva by testing a small sample of saliva from a student's mouth.

Hyperventilation can cause a change in the blood, raising the acidity (lowering the pH) and causing dizziness and fainting. The body then stops the excess breathing, and the blood pH returns to normal.

In the desert, where calcium carbonate dust in the air buffers the carbonic acid, the pH of rain may be neutral.

Scientists estimate that about two-thirds of acid rain is caused by nitrogen oxides, hydrogen sulfide, and sulfur dioxide from industry and automobile exhausts.

Possible demonstration: Place a drop of ink in a small quantity of water. All of the water should become colored. Place a drop of ink in a larger quantity of water, and the color is not noticeable. Experiment with the quantity of water in advance in order to have enough so that color will not show at the beginning of the experiment but will show after a reasonable number of drops.

"The solution to pollution is dilution" was a common theory a few years ago. Continue to drop more ink in the larger quantity of water until it turns color. Dilution as a solution to pollution will work only so long.

In Norway and Sweden fish have died in 6,500 lakes. In Ontario, Canada, over 1,200 lakes are now considered dead. In the Adirondacks more than 200 lakes are dead. East of the Mississippi about 16% of the lakes are showing signs of damage and 38% are endangered (little buffering left). About 21% of the rivers show damage and 21% more are endangered. Ontario may lose an additional 48,000 lakes in the next 20 years.

In some places acid smog is even more of a problem than acid rain. The cause is the same.

Common Acids and Bases

Acids:
- hydrochloric acid–HCl
- sulfuric acid–H_2SO_4
- carbonic acid–H_2CO_3

Bases:
- sodium hydroxide–$NaOH$
- calcium hydroxide–$Ca(OH)_2$

Acid rain

Some metal statues and some stone buildings appear to be melting. In some crystal clear lakes and streams there are no longer any fish. The cause: acid rain. Normal rain is slightly acidic (pH 5.6 to 6) because it picks up carbon dioxide from the air which dissolves to form carbonic acid.

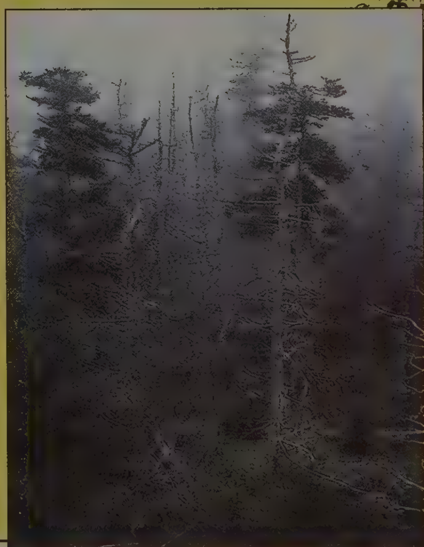
$$H_2O + CO_2 \longrightarrow H_2CO_3$$

Under normal circumstances any mildly acidic rain is neutralized by basic substances in the water or soil where it falls.

Automobile exhausts and the burning of coal and oil in industry release compounds containing sulfur and nitrogen. When these substances dissolve in atmospheric water, they form **acid rain.** When small amounts of these substances are put into the air, the harmful effects are seen near the industry that produced the pollution. To solve the problem, taller smokestacks are built. This puts the chemicals higher in the atmosphere and causes them to spread over greater distances before they fall as acid rain.

For a while the natural buffers in the soil and water could deal with the excess H^+ ions. Today, however, major industrial areas put so much acidic substances into the atmosphere that acid rain comes down in sufficient quantity to do major damage in large, downwind areas. Another solution is to remove the chemicals that cause acid rain before they are put into the air. This process, however, is expensive.

Today in some places rain has a pH of 2 (near that of automobile battery acid). With such high acidity the natural buffers in soils and waters are quickly used up, and the pH falls. The waxy covering of plants is removed by acid rain, exposing them to insects and fungal diseases. The acids affect soil nutrients, causing plants to die of



Answers–Review Questions 2A-1

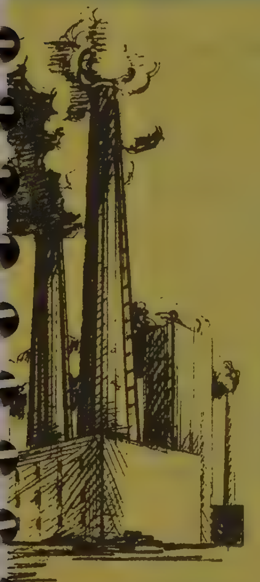
1. One must understand chemistry in order to understand the nature of biological structures and substances and the rules by which they function.
2. Matter is anything that occupies space and has mass (three phases: solid, liquid, gas). Energy is the ability to do work (kinetic–motion; potential–stored).
3. See Table 2A-1, p. 43.
4. The center of the atom (nucleus) is a cluster of positively charged particles (protons) and neutral particles (neutrons). Electrons (negatively charged particles) move constantly in levels or shells around the nucleus. The nucleus is relatively distant from electrons. In a neutral atom the number of electrons equals the number of protons; the number of neutrons varies, forming isotopes. The significance of electron configuration is that the arrangement of electrons is responsible for the type and strength of an atom's reaction with other atoms. Electrons are responsible for the binding and stability of atoms as the atoms form molecules.
5. (1) Covalent–atoms forming molecules share electrons; (2) ionic–electron transfer between atoms; forms ions (charged particles)

mineral starvation. As soil pH falls the kinds of organisms in the soil change, and in time the acidity gets so high that few organisms can live in the soil.

In freshwater lakes and streams, acidity causes the bones in many living fish to lose calcium. As muscles pull on the weakened bones, the fish become deformed. The eggs or young of some aquatic animals cannot survive the high acidity. In such places only an adult population of certain organisms exist. When these adults die there will be no replacements. In some beautiful, clear, blue lakes nothing lives except rare forms of algae.

Since what goes up in one country often falls in another, the acid rain problem is international. To be good stewards of the natural resources the Lord has given us, we must be concerned enough to do our part to help solve this environmental problem (see pages 483-97).

Review questions on right.



The effects of acid rain. Some kinds of trees are more acid tolerant than others. If the soil becomes too acidic, they will die.

Not all changes in matter are chemical changes. Adding heat to ice causes it to change its state. Such a change is a **physical change**–the process of altering the state of something, its appearance, or its combination with substances, but involving no change in electron sharing or giving.

A **mixture** is formed when two substances are combined without chemical bonding. Forming a mixture involves only a physical change. Since they are not chemically bonded, mixtures can be separated by heating or by mechanical methods. Water and sand do not have definite proportions as do chemically bonded compounds. You can have as much or as little sand in your water as you like. Mixtures keep the properties of the components of which they are made, not any of the new properties that would result if the components were united chemically.

Review Questions 2A-1

1. Why is an understanding of chemistry important for an understanding of biology?
2. Define the two components of the physical world.
3. What elements are essential to life? What are their element symbols?
4. Describe an atom. What is the significance of its electron configuration?
5. Name and describe the two primary types of chemical bonding.
6. Define and compare the following: an atom, an ion, a molecule, a compound, a mixture.
7. What things can a scientist determine (a) by studying a molecular (empirical) formula of a compound and (b) by studying a structural formula of a compound?
8. List and compare the characteristics of a chemical change and a physical change.

Facet 2A-1: Acids, Bases, and Buffers, pages 47-49.

1. Describe acid, and base; also explain what happens when the two are mixed together.
2. What unit of measurement tells the acidity or alkalinity of a substance? What range of readings indicate an acid solution? an alkaline solution? a neutral solution?
3. What are the causes and effects of acid rain, and why is acid rain a difficult problem to solve?

The organisms in some lakes are completely wiped out, while a nearby lake may have a normal pH reading and plenty of wildlife. The amount of natural buffers in the soil or substrates of the lakes often differs greatly. Some lakes in acid rain areas have a normal pH but have no life. Often this is because the snow holds the acid, but when spring comes, the acidity soars. In time, the buffers neutralize the acids, but the damage to the organisms has been done.

Visual 2A-3 can be used to teach and present examples of the characteristics of chemical and physical changes. Categorize the examples on the bottom of the chart. Chemical changes include burning wood, forming water, using a battery, baking a cake, making salt, and mixing an acid and a base.

Other examples of physical changes are molding clay, melting ice, boiling water, bending a nail, and blowing up a balloon.

Demonstration: Put a tea bag into hot water and ask if it is a chemical or physical change. *(physical)* Put Alka-Seltzer into water and ask if there is a chemical or physical change. *(chemical)* Drink the Alka-Seltzer and ask again. *(The chemical change of the Alka-Seltzer* base *in the stomach* acid *forms salt and water to the limit of the base consumed.)* Use as a transition to or a review of the *Acids, Bases, and Buffers* Facet.

6. **(1)** An atom is the smallest unit of an element that is still an element. **(2)** An ion is a charged atom, (+) or (–), with an unequal number of protons and electrons. **(3)** A molecule is two or more atoms bonded together; it is the smallest unit of a substance that retains the properties of that substance. **(4)** A compound is the result of binding of different elements which forms different substances (e.g., NaCl, H_2O). **(5)** A mixture is the combination of substances without chemical bonding.
7. **(a)** A molecular formula reveals the simplest whole-number ratio of the atoms in a compound. **(b)** A structural formula reveals the actual organization, binding, and overall structure of a compound.
8. **(1)** Chemical change–in definite proportions; new compounds formed or elements released; energy involved **(2)** Physical change–altering of state (solid, liquid, gas); change in appearance or combination with substances; no change in electron sharing or giving (bonding); may form mixtures (components retain natural properties)

Answers–Facet 2A-1

1. An acid is a solution with an excess of hydrogen ions, and a base is a solution with an excess of hydroxyl ions. When the two are combined, an acid and a base neutralize each other, forming water and a salt.
2. The pH scale is used to measure alkalinity and acidity. Numbers 0-6.9 are acidic, 7.0 is neutral, and 7.1-14.0 are alkaline.
3. Acid rain is believed to be caused by emissions into the air by industry and automobiles. Acid rain damages structures and can be harmful to living things. It changes the pH of soil and water once the natural buffers have been exhausted and thus changes the environment, altering the kinds of or-

kinetic: (Gk. KINEIN, to move)

thermodynamics: thermo- or therm- (Gk. THERME, heat) + -dynamics (DUNAMIS, power)

Hold a book above the floor and then drop it. Ask about kinds of energy. A book held in position above the floor illustrates potential energy (the energy of position); when released, the book falls, illustrating kinetic energy (the energy of motion).

Energy

Energy can be defined as the ability to do work. For our purposes, there are two types of energy: *kinetic**(kih NET ik) and *potential*. **Kinetic energy** is the energy of motion, such as falling, heat, light, and electricity. **Potential energy** is stored energy, like the energy found in a rock sitting at the top of a cliff, in a log waiting to be burned, or in a battery ready to be connected to a light bulb.

In each of these examples, potential energy can be converted into kinetic energy. Pushing the rock, igniting the log, or connecting the battery will start the change from potential to kinetic energy.

Kinetic energy can also be converted into potential energy. One of the most important conversions to take place on our planet is the one in which green plants absorb light energy from the sun and convert it into the potential chemical energy that is stored in sugar. Later, the plant and other organisms, including humans, will convert the stored chemical energy in sugar into the other forms of energy needed to carry on life.

The laws of thermodynamics*(THUR moh dye NAM icks) are man's statements of how energy

2A-5 *Sunlight is converted from kinetic energy into the stored energy of a sugar molecule by kelp, a large algae.*

changes occur. The *first law of thermodynamics* states that in any process energy is neither created nor destroyed. Energy can change from one form to the other, but there is always as much at the end as there was at the beginning of the process. The *second law of thermodynamics* states that whenever energy is used (changed from one form to the other), some of it is wasted (though not destroyed). That is, not all energy put into something is still there at the end of the transfer. Some of the energy radiates out of the object, usually as heat or light. Eventually this wasted energy goes into space. But because of the vastness of space, all the energy that has gone into it has not yet diminished its darkness or even raised the temperature of outer space to even near the freezing point of water.

A natural corollary, or parallel, to the second law of thermodynamics is the *law of degeneration:* in all natural processes there is a net increase in disorder and a net loss of usable energy. For reactions such as burning a piece of wood, it is easy to see that the end products (carbon dioxide, water vapor, and ashes) contain much less energy and are in a much more random arrangement of molecules than before the burning took place. This increase in randomness and loss of usable energy is an increase in **entropy** (EN truh pee).

See *Basic Chemistry for Christian Schools®* or *Physics for Christian Schools®* for a discussion of the laws of conservation and degeneration.

Entropy is the measure of the decrease in usable energy.

ganisms that live there. Because the source of the pollution that causes the acid rain may be many miles away and because the pollution is released by so many different sources, it is difficult to deal with.

Some reactions, however, appear to contradict the law of degeneration. Green plants use sunlight energy to make sugar from water and carbon dioxide. This conversion of kinetic energy to potential energy and of simple substances to a larger more orderly substance requires more energy than is left in the new molecule, and is a result of the *law of conservation*. This process permits the growth and reproduction of plants.

At first glance, the law of degeneration and the law of conservation appear to be in contradiction. Actually, however, they work in God-ordained harmony. For example, living things build complex substances according to the law of conservation. In time, the living organism will either use the energy stored in the molecule or release the energy in the form of heat or motion. When the organism dies, energy is released as its molecules decompose. The use or release of the energy by the organism is in keeping with the law of degeneration. This balance will be discussed in more detail throughout this text.

Kinetic molecular energy

Are you surprised to be told that each of the molecules that make up this book is wiggling? Unless you are in a room at absolute zero (−273.15° C or −459.7° F), all the molecules which make up the substances around you have a certain amount of heat, the energy of motion. Even solid substances, therefore, are composed of moving molecules.

The amount of heat in a substance determines how fast its molecules are moving and its physical state. In ice, for example, molecular motion is slight; the individual water molecules are barely moving. In liquid water, however, the movement is greater because the substance has more heat. And when water molecules are heated to 100° C (212° F–the boiling point of water), they are so active that they leave the surface of the fluid as water vapor, a gas.

The fresh air you are breathing is an example of a mixture of gases (oxygen, carbon dioxide, nitrogen, water vapor, and others) which are not chemically bonded to one another. At room temperature the moving molecules press against each other, against the walls, and all surrounding objects. If the temperature drops sufficiently (reducing the movement of the molecules), some of the molecules will settle out. First, the water vapor leaves the mixture and condenses. If the temperature drops further, carbon dioxide (heavier than most of the other gases) will begin to form a layer near the floor of the room as its molecules move less and less. If the temperature were low enough and if the pressure were sufficiently increased, carbon dioxide would turn to a liquid, just as the water vapor did. At various lower temperatures the other gases would also become liquids. The mixture of gases called air would then be separated by the physical process of cooling.

Diffusion

Diffusion* is the net movement of molecules from an area of higher concentration of a substance to an area of lower concentration of that substance. *Net movement*, in this definition, means the number of molecules that moved from the higher concentration area *minus* those that moved back into the higher concentration area. When there are no longer places of higher and lower concentrations, a state of **equilibrium*** (EE kwuh LIB ree um) has been reached, and diffusion stops. Let us consider an example.

If a bottle of perfume is left open in the center of a room, the molecules of the perfume will diffuse: they will leave the fluid and enter the air. A few of the molecules of perfume will leave the air and return to the perfume in the bottle. These molecules are going from an area of lower concentration to an area of higher concentration and thus are not part of the diffusion; they are not part of the *net movement*.

At first, the area around the perfume bottle will have a strong odor because this area will have the greatest concentration of perfume molecules. In time, however, even the farthest corners of the room will have perfume molecules. If left alone, the perfume will completely evaporate as all the perfume molecules enter the air, and the entire room will eventually be filled evenly with the scent of the perfume. Equilibrium will have been reached.

diffusion: dif-, dis-, di- (L. DIS, apart) + -fusion (FUNDERE, to pour)

equilibrium: equi- (L. AEQUUS, equal) + -librium (LIBRA, balance)

The law of conservation parallels a Christian's understanding of the sustaining (Ps. 104) and the upholding (Heb. 1:3) power of God in nature.

Consider demonstrating molecular motion by cutting a hole (approximately 6" × 6") in the lid of a small cardboard box, placing it on the screen of the overhead projector, and putting several marbles inside the rim. Making the marbles move by jiggling the rim illustrates what the addition of heat does to molecules in motion. The more jiggling there is, the faster and more violent the motion of the molecules is.

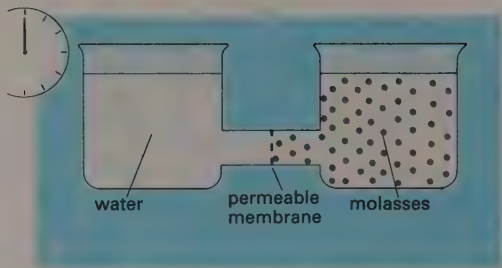
The driving force behind diffusion is the kinetic motion discussed earlier.

Place a covered dish of ammonia in the center of the classroom. Uncover it at the proper time. Note the increasingly wider circle of "pinched noses." Use this to discuss equilibrium.

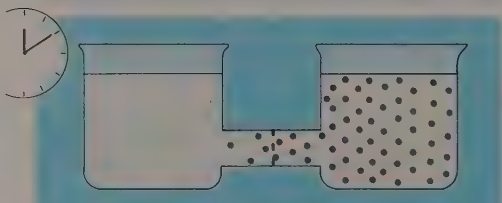
semipermeable: semi- (L. SEMIS, half) + -permeable (PERMEARE, to pass through)

Place a drop of food coloring in water at the beginning of a class period. By the end of the period, it will have completely diffused throughout the solution. Ask the students how the process could be speeded up (stirring, heating, or adding more food coloring, for instance). Discuss the processes.

Ask the students how a cube of sugar can be made to dissolve more rapidly in a glass of water. An easy method of increasing the diffusion rate is to heat the sugar and water. The more rapidly the molecules of both sugar and water move, the more quickly diffusion occurs. Another method is to grind up the sugar cube. Since molecules can dissolve only from a surface, diffusion can take place more rapidly if the surface area of a substance is increased. Probably the most common method of getting sugar to diffuse more rapidly in water is to stir the mixture. Since diffusion slows down as the solution approaches equilibrium, diffusion would be slow near the sugar cube where the concentration of sugar molecules is high. Stirring moves this high-concentration area away and brings the surface in contact with water of a lower sugar concentration. The diffusion pressure is then high again.



In the above diagram water has been placed on one side of a cloth and molasses on the other. Because the water side has no molasses molecules and the molasses side has relatively few water molecules, the **concentration gradient** (GRAY dee unt) is high for water on one side and high for molasses on the other. The concentration gradient is the difference between the numbers of one type of molecule in two adjacent areas. A high concentration gradient indicates that the difference is very great; a low concentration gradient indicates that there is little difference.

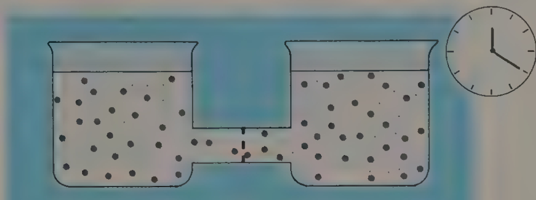


diffusion taking place

The **diffusion pressure,** based on the relative concentrations of water and molasses molecules, is very high in the above figure. Diffusion occurs rapidly when the diffusion pressure is high. Since the molecules of both water and molasses can easily pass through the cloth, diffusion happens in both directions.

After a period of time, the number of water molecules and the number of molasses molecules on each side even out, and diffusion slows. The individual molecules are not slowing down, though; they continue to move because of the heat they possess. As long as the temperature remains the same, the molecules will continue to move at the same rate. Diffusion slows down as the concentration gradient decreases.

As diffusion continues, the number of molecules moving out of the areas of high concentration approaches the number of molecules moving *into* the areas of high concentration. That is, about the same number of molasses molecules are entering and leaving the molasses side. The same is true for the water molecules. Diffusion, you re-

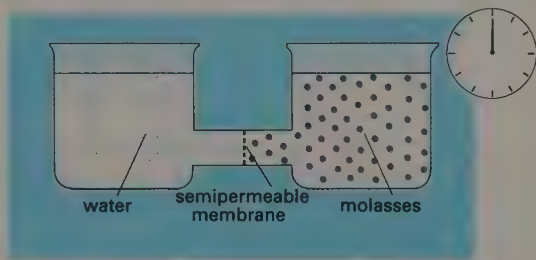


equilibrium

call, is the *net movement*. Although these molecules continue to move, the *gain* in number on the lower concentration side is not as great as it was. As the concentrations of water and molasses get closer, diffusion presssure decreases, and diffusion slows down. In time, equilibrium will be reached.

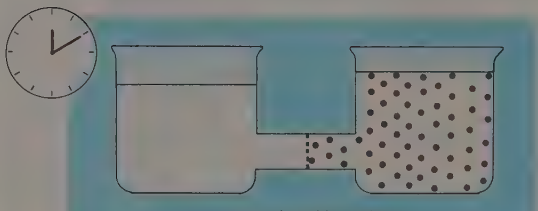
Osmosis

Suppose that instead of cloth, a membrane having very small pores was placed between the molasses and water in the example of diffusion discussed previously. If the membrane's pores are so small that they will permit the water molecules to pass through but will not permit the larger molasses molecules to pass through, it is a **semipermeable*** (SEM ee PUR mee uh bul) **membrane** (or *selectively permeable membrane*) be-

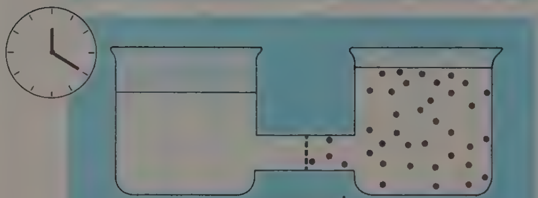


cause it is permeable to some things but not to others. Living organisms have many selectively permeable membranes.

If the water and molasses are separated by a semipermeable membrane, the concentration gradients for both water and molasses are very high. Water molecules move into the molasses. Diffusion of water molecules through a semipermeable membrane is **osmosis*** (ahz MOH sis). The large molasses molecules, however, are not able to move into the water because of the small size of the pores in the semipermeable membrane. The water level falls as water molecules move to the molasses side, forcing the level higher on the molasses side.



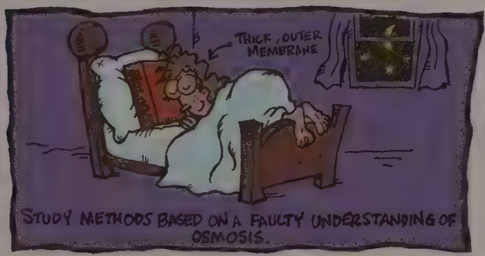
osmosis taking place



no osmosis
no equilibrium reached

Will this unequal movement of water molecules into the molasses ever produce an equal concentration of molasses and water molecules on each side? That type of equilibrium is impossible in this case. Nor can the water molecules continue going through the membrane until all the water has moved to the molasses side even though a continuous concentration gradient exists because the molasses cannot enter the water. The *net movement* of water molecules into the molasses will decrease. Gravity pulling down on the molasses side, along with other forces, will in time equalize the diffusion pressure of the water molecules. At that point osmosis, the *net movement* of water molecules through a semipermeable membrane, will cease, even though the concentrations are not equal. Molecules of water will continue to move back and forth across the membrane, but there will be no net gain or loss.

Diffusion and osmosis are two of the most important physical processes that affect organisms. The materials of a cell exist as a colloid inside a semipermeable membrane. The proper concentration of **solutes*** (dissolved substances) inside and outside that membrane is highly critical to the existence of the cell. A good example of this fact is the effect on a person who drinks seawater. The concentration of ions in the salt water is higher than the ionic concentration of substances inside the cells of the human digestive tract. The diffusion of salt ions into, and the osmosis of water out of, these cells soon kills the cells. If too many cells in the digestive system are affected, it can cause serious disorders and even death.



Potential energy of a molecule

The energy required for diffusion and osmosis and the energy which keeps the particles of a solute in solution are kinetic energy. It is the movement of molecules which gives diffusion and osmosis, as well as solutions, many of their qualities. Each molecule, however, also has potential energy held in its chemical bonds. A discussion of chemical reactions is necessary to understand this.

Chemical reactions fall into 2 basic groups: those that require or absorb heat are called *endothermic*,* and those that give off heat are called

osmosis: osmos- or osmot- (Gk. OSMOS, thrust)

solute: (L. SOLUTUS, to loosen)

endothermic: endo- (within) + -thermic (heat)

One can demonstrate osmosis over a period of two or more class sessions by using an egg's semipermeable membrane. Carefully crack and remove the shell from the large end of a raw egg, exposing the shell membrane. Drill a small hole through the opposite end of the egg, attach a clear straw or glass tube, and seal it in place with wax or putty. Place the exposed membrane in a beaker of water, being careful to secure the egg in an upright position. Over a period of several hours, water will pass through the membrane, pushing the albumen, and eventually the yolk, up the straw.

Stress this example because it is one of the biological reasons for learning about diffusion and osmosis. There will be many more examples in the future. Another example the students should be able to grasp involves gargling for sore throats. The bacteria that cause many sore throats are combatted by gargling with salt water. Water diffuses out of the cells into the concentrated salt solution, killing the bacteria. Throat cells have membranes designed to deal with the higher concentration of salt ions.

exothermic: exo-, ex-, ef-, e- (Gk. EXO, outside of) + -thermic (heat)

catalyst: cata- (Gk. KATA, intensive) + -lyst or -lysis (LUEIN, to loose, break apart)

In breaking these bonds, energy is released; thus, an exothermic reaction has occurred.

Here energy is produced; so it is listed as a product.

Here energy is required for the reaction to occur; so it is listed as a reactant.

Activation energy can be compared to an initial push to cause things to start rolling. The activation energy for an exothermic reaction may be large or small but must be supplied in order for the reaction to proceed.

Catalysts do not affect the amount of energy released or the rate at which the individual reactions occur. They make the possibility of a reaction greater by lowering the activation energy necessary for that reaction to occur.

The standard laboratory preparation of oxygen can be used to illustrate a reaction which requires a catalyst.

$$2\ KClO_3 \xrightarrow{MnO_2} 2\ KCl + 3\ O_2 \uparrow$$

*exothermic.** Heat is required to make cake batter solidify into the cake you eat; this is an endothermic reaction. A piece of wood gives off heat (as well as light) as it burns; this reaction is exothermic.

Let the letters ''A'' and ''B'' represent two elements or compounds before they chemically react with one another, and let ''C'' and ''D'' be the compounds that are the result of the chemical reaction. The reaction would be written like this:

$$A + B \longrightarrow C + D$$

This chemical equation is read, ''A plus B yields the products of C plus D.'' The energy given off or absorbed in a reaction is often represented in a chemical equation. If the reaction between A and B is exothermic–giving off energy–the reaction is written like this:

$$A + B \longrightarrow C + D + \text{energy}$$

Assume that the reaction between ''W'' and ''X'' requires energy to become ''Y'' and ''Z.'' This endothermic reaction is written:

$$W + X + \text{energy} \longrightarrow Y + Z$$

But where does the energy required for baking a cake (or for any other endothermic reaction) go? In the endothermic reaction above, energy does not appear on the products side of the arrow. Does all the energy therefore escape into the atmosphere? No. The products *contain* some of the energy. From where does the energy given off by a burning piece of wood (or from any other exothermic reaction) come? In an exothermic reaction the energy released was *contained* in the substances that entered the reaction.

Whenever atoms get, give, or share electrons, energy changes occur. Large molecules are usually formed by combining smaller molecules, and this requires energy. Generally, in living things, to have the molecules combined by sharing electrons, energy is supplied to some of those electrons. With the exception of the energy which escapes, the energy supplied is actually still there as chemical bond energy.

Think again of the cake. The substances mixed together to form the batter need to combine in order to become a cake. This requires heat energy. When molecules break apart, the bond energy is released. When wood burns, the large molecules are being broken down to carbon dioxide, water, and other small molecules. This breaking apart of molecules releases large amounts of energy as heat and light.

In the previous chapter, the need for a constant supply of energy was listed as one of the attributes of life. One of the reasons for this requirement is that living organisms must constantly make large, complex molecules. These molecules are the very substance of the organism itself. The food you eat supplies you not only with the energy you use to move but also with the energy necessary to build the complex molecules which form your cells.

Catalysts

Many reactions are spontaneous; that is, whenever the proper substances contact one another, the reaction immediately takes place. For instance, the combining of sodium and chlorine is spontaneous. Other reactions, however, require energy to start them. Paper does not burn when only oxygen is present. The molecules in a piece of paper must be heated to a certain point before the reaction will start. Once started, this reaction is exothermic and supplies the heat necessary for other molecules to carry on the reaction as well. The heat necessary to start the burning reaction is called the **activation energy.** Activation energy is often in the form of heat, but for other reactions it may be electricity, light, or some other form of energy.

Some reactions like burning wood happen very rapidly, even explosively. Others, like iron and oxygen forming rust, happen slowly. In order to control reactions, scientists use **catalysts*** (KAT uhl ists)–substances which affect the rate of a reaction but are not changed in the reaction. Catalysts seem to affect reactions by changing the activation energy required for the reaction.

Specific chemicals serve as catalysts for specific reactions, so there is not one catalyst for speeding up all reactions and another for slowing down all reactions. Many chemical reactions have no known catalyst. In a chemical equation, the

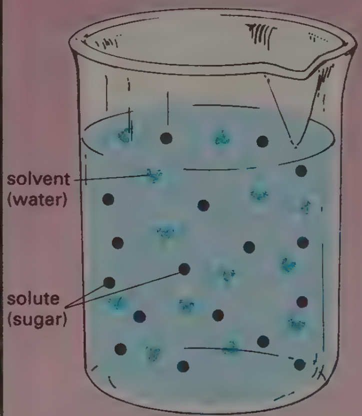
Solutions, Suspensions, and Colloids

Living things are mostly water. The average human body contains 12 gal. of water. The other substances that make up protoplasm are in some way dissolved or suspended in water. The characteristics of the watery combinations that make up living things are vastly different, depending on what is in the water. Some things, like oils and large carbohydrates, do not mix well with water, while others, like sugars and salts, mix very well. Many proteins have some Jell-O-like properties when they are mixed with water.

A change in the concentration of the solutes in the solution in which these fish swim could kill them.

Solutions

When sugar is dissolved in water, it forms a **solution.** A solution is a



A solution of sugar water

homogenous* (HOH muh JEE nee us) mixture of one or more substances in another substance. A homogeneous mixture is one that is the same throughout. The sugar molecules, for example, are small enough to be separated by water molecules. The sugar will not settle out, and the mixture will be homogeneous. Sugar water is, therefore, a solution.

The substance which is dissolved (sugar) is called the **solute,** and the substance in which it is dissolved (water) is called the **solvent.** Solutes are generally made of ions or small molecules, and often several different solutes will be in a single solution. Because water is the solvent in many solutions it is sometimes called the *universal solvent.*

The quantity and kinds of solutes in water are significant for aquatic organisms. Freshwater has fewer solutes than salt water. Most freshwater organisms if put in salt water will have problems with the higher solute concentration, and many will die. The reverse is true when putting saltwater organisms in fresh water.

Organisms must also maintain a specific internal solute/solvent ratio. Any injection into your blood stream must have the same solute/solvent ratio as your blood or your tissues may be damaged. When a person is fed by putting sugar into his blood stream the solute/solvent ratio of sugar and water going in must be the same as his blood or he may die.

Solutions put into a person's blood must have the same concentration of solutes as blood.

homogeneous: homo- or homeo- (Gk. HOMOIOS, same) + -geneous (GENOS, stock, race, or kind)

This Facet presents the characteristics of solutions, suspensions, and colloids and how they relate to living things. This material is crucial to understanding the concepts of substances entering cells and the properties of the cytoplasm of a cell.

The terms **solution, homogeneous, solvent, solute, suspension, colloid, gel phase,** and **sol phase** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Other terms students may need to know include *universal solvent, reversible phase colloid,* and *nonreversible phase colloid.*

Suspensions include oil and vinegar dressing, muddy water, and fine aerosol mists (e.g., air fresheners). Adding heat increases the molecular movement which keeps the particles in the medium. For example, in hot soup the oils and water "mix," but when cool, the oils form a layer on the surface of the water.

Solute = substance dissolved; solvent = dissolver.

Answers–Review Questions 2A-2 *(p. 57)*

1. **(1)** Kinetic energy is energy of motion (e.g., falling, heat, light, electricity). **(2)** Potential energy is stored energy that can be converted to kinetic energy (e.g., energy stored in elevated objects, unburned logs).
2. **(1)** The first law of thermodynamics–In any process, energy is neither lost nor created; it can change forms. **(2)** The second law of thermodynamics–Whenever energy is used, some is wasted but not destroyed.
3. The amount of heat in a substance determines how fast its molecules will move and what state it is in. Molecules

suspension: sus- (L. SUB-, under) + -pension (L. PENDERE, to hang)

colloid: coll- (Gk. KOLLA, glue) + -oid (EIDOS, form or shape)

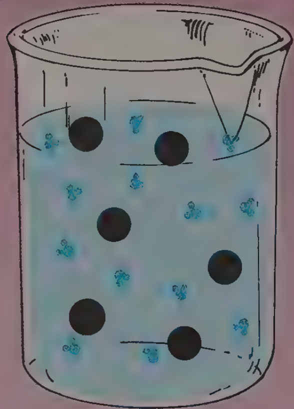
Additional information about solute concentrations affecting organisms can be found on pages 80, 84-88, and 402. Tea with sugar and lemon in it would be a solution made of one solvent (water) and at least three solutes.

The temperature of the solution greatly affects the amount of solutes that can be dissolved in a solution. Generally, more molecular movement (heat) in the solution means that more solute molecules can be in the solution. A saturated solution is one which has as many solute molecules as it can hold at a given temperature. If a saturated solution cools, some of the solute will settle out, usually forming crystals on a surface.

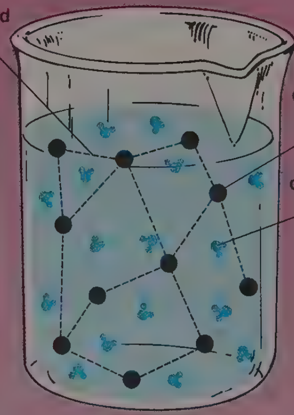
Possible demonstration: Hot water (near boiling) with a large amount of sugar dissolved in it will be clear and homogeneous. Allow it to cool overnight with a string or stick in it. The string or stick will become coated with the sugar that can no longer remain in the cooler water. ▶

Suspensions

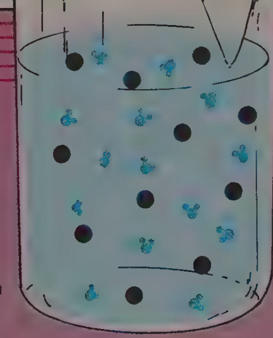
A **suspension*** can be made by placing flour in water. After the mixture is stirred, flour is suspended in the water; but if the mixture is allowed to stand, the flour will soon settle to the bottom. In a suspension the molecules of the suspended material do not form a homogeneous mixture. They are so large that the molecular movement of the solvent is not sufficient to keep them up; so they settle to the bottom.



A suspension of flour water



A colloid in gel phase



A colloid in sol phase

Some of the substances and structures in protoplasm are suspended particles. Living protoplasm is constantly moving which keeps the solution "stirred up" and the particles suspended.

Colloids

Protoplasm itself, however, is not just a solution with some suspended materials in it. Protoplasm is a specialized mixture called a **colloid.*** The size of the particles of a colloid is somewhere between that of the particles in a true solution and the particles in a suspension. In a colloid the solvent is properly called the *dispersion medium,* and the solute makes up the *dispersed particles.* In a colloid the dispersed particles are not small enough to be a solution nor large enough to settle out quickly. Colloids are often in one of two different stages: the semisolid state called the **gel phase** or the fluid state called the **sol phase.**

Gelatin mixed in water (such as in Jell-O) is a common colloid which is affected by temperature. Lower temperature causes the gelatin's dispersed particles to line up and form weak bonds. The gelatin becomes a semisolid gel. Heat breaks the bonds between the particles, and the colloid enters the sol phase. In other colloids, substances such as salt or factors such as pressure, pH, or concentration of other ions can change the substance from one phase to another.

Gelatin is a *reversible phase colloid:* it can change back and forth between sol and gel. Egg white is a colloid that, when heated, is changed into the gel phase.

But egg white is a *nonreversible phase colloid:* once the dispersed particles have become bonded and it is a gel, it does not return to the sol phase.

All living materials are colloids. The protoplasm that makes up a cell is a complex reversible phase colloid. This can be easily demonstrated. Put your hand over a muscle and flex the muscle. The firmness you feel is the gel phase of your muscle colloid. Now relax. The muscle enters the sol phase.

Temperature and many other factors can change the protoplasmic colloid from one phase to another. Electric shock causes muscles to become gels and forces your body to jerk as it does so. Heat can cause the protoplasmic colloid to enter the sol phase.

Review questions on next page.

move more rapidly as heat increases and more slowly as heat decreases. Generally, colder temperatures cause substances to exist as solids or liquids (e.g., water as ice), and higher temperatures cause them to exist in gaseous states (e.g., water as vapor).

4. Diffusion is the net movement of molecules from a place of high concentration to a place of low concentration. Examples would include an odor coming from another room (like baking) and making tea or coffee.
5. Diffusion can be any substance moving into another. Osmosis involves the movement of water only. Diffusion may or may not be through a membrane; osmosis is always though a membrane.
6. The kinetic (heat) energy of the substance is the movement (energy) needed for osmosis or diffusion. The colder a substance is, the more slowly it diffuses; the warmer it is, the faster.
7. **(1)** Endothermic (absorbs heat); **(2)** exothermic (releases heat)
8. An enzyme **(1)** affects rate of reaction (changes energy of activation), and **(2)** is not changed itself in overall reaction.

Answers–Facet 2A-2

1. **(1)** A solution is a homogenous mixture; the solute particles are small enough to be separated by the solvent particles and, therefore, remain suspended (do not settle out). **(2)** In a suspension, molecules placed in a solvent do not form homogeneous mixtures; they are too large to be kept in solution, and they settle out. **(3)** In a colloid, the particle size is between that found in a solution and suspension. The particles are dispersed; they are too large to form a true solution but not large enough to settle out quickly. Often there are two states: sol (fluid) and gel (semisolid).
2. A reversible phase colloid is one which can repeatedly change back and forth

catalyst is indicated over the arrow. A chemical reaction for which much energy is required is written:

$$A + B + \textbf{Energy} \longrightarrow C + D$$

With a catalyst the same reaction might look like this:

$$A + B + \text{energy} \xrightarrow{\text{catalyst x}} C + D$$

You have often heard of a person "burning" up his food or "burning" off fat. You may have thought these expressions were merely figures of speech, but they are accurate. The food you eat is combined with oxygen for the release of energy, almost as if you had set your food on fire. The difference, which prevents you from cooking yourself as you digest your dinner, is a complex system of organic catalysts. These catalysts lower the activation energy required for the reaction and slow down the reaction so that the energy is released in small, usable amounts. The process could be written like this:

$$\text{Food burning: } O + P \longrightarrow \textbf{ENERGY} + Y + Z$$

$$\begin{aligned} \text{Digestion: } O + P &\xrightarrow{\text{catalyst a}} \text{energy} + Q + R \\ Q + R &\xrightarrow{\text{catalyst b}} \text{energy} + S + T \\ S + T &\xrightarrow{\text{catalyst c}} \text{energy} + U + V \\ U + V &\xrightarrow{\text{catalyst d}} \text{energy} + W + X \\ W + X &\xrightarrow{\text{catalyst e}} \text{energy} + Y + Z \end{aligned}$$

Biological Terms

chemistry	ionic bonding	*Energy*	semipermeable membrane	neutralize	colloid
Matter	covalent bonding	energy	osmosis	pH	gel phase
matter	compound	kinetic energy	solute	buffer	sol phase
element	molecular formula	potential energy	activation energy	acid rain	
atom	structural formula	entropy	catalyst	solution	
proton	molecule	diffusion	*Facet*	homogenous	
neutron	chemical change	equilibrium	acid	solute	
electron	physical change	concentration gradient	base	solvent	
ion	mixture	diffusion pressure		suspension	

Review Questions 2A-2

1. Name, describe, and give examples of two basic forms of energy.
2. What are the first and second laws of thermodynamics?
3. Describe how heat affects the molecules of a substance.
4. Describe diffusion and give two examples of how it occurs in the home.
5. List two main differences between diffusion and osmosis.
6. Where does the energy needed for the movement of molecules in diffusion and osmosis come from?
7. According to the heat energy involved, what are the two basic types of chemical reactions?
8. List two attributes of a catalyst.

Facet 2A-2: Solutions, Suspensions, and Colloids, pages 55-56.

1. List and compare the characteristics of a solution, a suspension, and a colloid.
2. What is meant by a reversible phase colloid and a nonreversible phase colloid?

Thought Questions

1. Give an example of the law of conservation and the law of degeneration working opposite each other.
2. Does the death of an organism result in increased or decreased entropy? Explain.
3. Give two reasons living things need energy and describe how they illustrate the law of conservation.
4. List several examples of diffusion and several examples of osmosis.
5. When something diffuses to the state of equilibrium, is that an example of an increase in entropy? Explain.
6. Does a catalyst help or hinder an increase in entropy? Explain.

Stress this example of catalysts. The reason for learning about catalysts is to introduce enzymes. If students understand the concept here, it makes the teaching of enzymes easier.

▶ Possible demonstration: When jelly is at room temperature, it is in the gel phase. When a spoonful is warmed, it enters the sol phase. Chilling it will cause it to return to the gel phase. Peanut butter does the same thing when spread on warm toast. Other "kitchen colloids" include mayonnaise, pudding, marshmallows, whipped cream, and milk. Not all of these have both gel and sol phases in their "kitchen" forms.

The reason the muscle does not "flow away" when it is relaxed is that other structures hold it together. The comparison to a water balloon is simplistic but can be used.

The protoplasm colloid consists predominately of solids (proteins, carbohydrates, and some fats) in a liquid. Other such colloids include paint and pudding. Colloids also include liquids in a gas (fog, clouds, mist), solids in gas (smoke, dust in the air), gas in liquids (foams of shaving cream, whipped cream), liquids in liquids (milk, mayonnaise), gas in solids (Styrofoam, marshmallows), and liquids in solids (cheese, butter). Some of these have both sol and gel phases; others do not.

Answers begin on page 55.

from sol to gel as the proper stimuli are applied. A nonreversible phase colloid can change its phase only once.

Answers–Thought Questions

1. As a young organism grows and reproduces, both conservation and degeneration are obvious in its processes, but the conservation dominates degeneration. As the organism ages, the dominance of degeneration over conservation becomes obvious.
2. Increased entropy. After death, cells disintegrate and molecules become more and more disordered.
3. Living organisms require energy for cellular work, such as cell division and protein synthesis. These energy-requiring processes enable the organism to grow and reproduce (conservation).
4. (1) Diffusion–gas spreading out from a leak; sugar dissolving in iced tea; spraying air freshener into a room
(2) Osmosis–water moving through plant roots, stems, and leaves; water moving from spaces between cells into blood capillaries; absorbing water from stomach and intestines into blood capillaries; water on wilted vegetables making them crisper
5. No. It indicates that the net movement of a given substance in any direction is zero.
6. It could do either. During anabolism there is a decrease in entropy; during catabolism there is an increase.

2B–Organic Chemistry

biosynthesis: bio- (life) + -syn-, -sym-, -syl-, -sys-, or -sy- (Gk. SYN, with, same, or together) + -thesis (to place)

vitalism: (L. VITA, life)

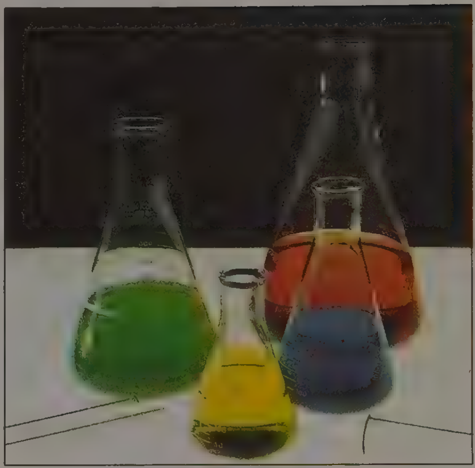
The elements C, H, O, and N are the major constituents of most organic compounds.

Living organisms make **organic** compounds. Many of these compounds are very large, complex molecules. Though some of the simpler ones are synthesized in laboratories, under normal circumstances most organic compounds are the result of **biosynthesis,*** the putting together of substances by living things.

Biosynthesis is essential to life. If a sculptor wants his statue to be larger, he adds more clay, bronze, or whatever makes up his statue. But if a living organism is to grow, it cannot just apply more of the material of which it is made. You do not spread layers of raw meat on your body in order to increase your physical size. That meat must be broken down into its component parts (digested) and then put back together so that it is your flesh, not the flesh of some other organism.

Headlines occasionally say that life has been created in a test tube. Those misleading headlines are written to get attention. A close reading of the article (if it is written accurately) reveals that the new development falls far short of creating life in a test tube. Usually a scientist has simply manufactured another organic compound in the laboratory. Examination often reveals that an elaborate apparatus was used. To duplicate biosynthesis–even of small organic substances–man must use large amounts of energy and special procedures and equipment. Each time a scientist employs sophisticated techniques to synthesize an organic compound, he indicates how unlikely it is that life could *spontaneously* generate in a test tube, much less in a legendary prehistoric pond.

Not only must *one* organic compound be made, but literally thousands of different ones must be made in large quantities, all at the same time (for many of them are very unstable), and all in the same place. Then they have to be given life. Will life just happen if all the chemicals are right? Even those scientists who attempt to create life in a test tube admit that their chemicals need some special "starting" force. In the evolutionist's prehistoric pond, a bolt of lightning is supposed to have started life. Regardless of thunderbolts or special startings, life is more than the proper alignment of the correct chemicals. **Vitalism*** is the theory that life is more than the chemicals which make up living things.



2B-1 *Chemistry is a vital part of biology.*

Is it possible for a living thing to be assembled from nonliving substances in a laboratory? At the time of this writing it has not been done. Many people who believe in vitalism believe it cannot be done. Life, the Scriptures tell us, is the creation of God. But the Bible does not tell us that man will not be able to put together a living thing. If, by using elaborate equipment and special manmade chemicals, scientists do form a structure that can be considered alive, does this support spontaneous generation and evolution? No. The use of the equipment, the manmade chemicals, and man's intelligence to form the living structure actually support the concept of a special creation of life by God, not a happenstance origin of life.

Organic compounds

Organic chemistry is often called carbon chemistry. Every organic compound has carbon in it, usually in conjunction with large quantities of hydrogen, and frequently with oxygen. Carbon, having only four electrons in its outermost shell, can form bonds with four other atoms. Often these

2B–Organic Chemistry

Notes–Chapter 2B

A knowledge of organic chemistry is essential in all areas of biological study. To high school students, however, organic chemistry may seem useless and confusing. To increase interest in this material, give practical applications that relate it to the real world, and avoid getting too technical.

Do not overlook the sentences that explain what an organic compound is used for in an effort to teach structure or bonding. After spending a few minutes on some "heavy" concept, apply the concept to living things. This, followed by the comment "and we will see other examples of this later in the course," will go a long way toward keeping the class and the study of biochemistry alive.

The structure and replication of DNA and the manufacturing of RNA are all that should be covered about nucleic acids at this point. Chromosomes, mutations, and the manufacturing of proteins are covered in some detail later in the text in other discussions. A grasp of these later topics, however, requires a thorough understanding of the structure of DNA and RNA and their relationships.

It is also advantageous not to put all of this rather difficult material together. By being introduced to the nucleic acids here and then reviewing them and going on, students seem to understand the entire concept better. The teacher can also answer the almost inevitable "Why do we have to learn DNA?" with a brief explanation and then a "You'll find out when we study it again later. For right now, all you need to know is . . ."

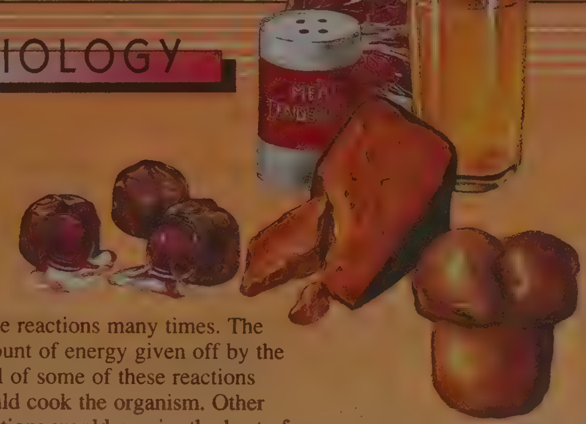
Facet–Chapter 2B

The single Facet on enzymes is essential material and should be covered thoroughly. Knowledge of what enzymes are and how they operate is necessary for understanding not only this chapter but also much of the material in later chapters.

2B-1 FACETS OF BIOLOGY

Enzymes-The Keys to Life

To some people **enzymes*** are those things which digest their food and somehow eat dirt in their laundry. It is true that a series of digestive enzymes break down foods to soluble nutrients that can be carried in your blood. Also, enzymes produced by various bacteria are used in detergents to break apart types of "grease and grime" so that they can be carried away in rinse water. Enzymes are even used in paper making, medicines, manufacturing textiles, clearing fruit juices, making sugars, forming cheeses, baking bread, tenderizing meats, and making soft-centered candy.



All living things must carry on thousands of chemical reactions, each one requiring or giving off energy. Living things must repeat these reactions many times. The amount of energy given off by the total of some of these reactions would cook the organism. Other reactions would require the heat of a flame to have them happen. Enzymes permit these reactions without the dangerous energy levels.

Generally, enzymes are proteins which serve as *organic catalysts*. By affecting the activation energy, catalysts slow down or speed up chemical reactions. Enzymes affect the energy levels needed or given off by chemical reactions in living things.

❑ The illustration on page 60 shows how an enzyme operates. From left to right the drawing represents the kind of enzyme which breaks a chemical apart. One part of the surface of the enzyme is called the *active site*. The active site fits with the shape of the *substrate*, which is the compound or compounds upon which the enzyme will react. The combination

Characteristics of Enzymes

❑ *Enzymes are proteins.* Although, there are exceptions, most enzymes are proteins. Proteins as enzymes are discussed on pages 64-65.

❑ *Enzymes are highly specific.* The enzyme that catalyzes the reactions between two sugar molecules will deal only with those two sugar molecules or with molecules that are almost identical to them.

❑ *Many enzymes require energy to perform their functions.* Without the proper supply of energy, enzyme reactions cease; therefore, life ceases.

❑ *Many enzymes release energy as they perform their functions.* Normally, the amount of energy released in a single enzymatic reaction is small. This energy can therefore be trapped and temporarily stored for use in reactions that require energy. Because the amount of energy released during enzymatic reactions is controlled, cells are not destroyed by too much heat energy being released at one time.

❑ *Enzymes often require coenzymes.* All **coenzymes** are nonprotein substances which fit into or affect the active site so that it accepts the substrate properly. Without an adequate supply of coenzymes, enzymes do not function. Some important coenzymes are vitamins.

❑ *Enzyme action is affected by heat, radiation, pH, chemicals, and other things.* Any of these can cause the enzyme to function improperly or not at all, thereby causing illness or death.

❑ *Enzymes most often work in series.* A molecule of sugar, for example, is broken down by dozens of different enzymes in succession. Each one may break off or add an atom or molecule or change the shape of the substrate.

enzyme: en- (in) + -zyme (ZUME, leaven)

This Facet presents a description of enzymes as essential organic catalysts. This Facet is crucial to understanding the organic chemistry of this chapter and several future chapters (cellular functions and human physiology). It is suggested that the students read this Facet and that the teacher cover the material in class lecture.

The terms **enzyme** and **coenzyme** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

It is important for students to understand these characteristics of enzymes. These characteristics will provide answers to several of their future questions. Present the concept now, telling the students that it will be more meaningful to them later. Be careful not to dwell on these characteristics because they can become boring. Stress the functioning of enzymes, and then present this list.

Objectives–Chapter 2B

- ❑ Define *organic chemistry*.
- ❑ List the major kinds of organic compounds and describe their basic functions.
- *❑ List several properties of enzymes. Describe the function of enzymes.
- ❑ Describe the structures of carbohydrates, proteins, lipids, and nucleic acids; discuss several functions each has in living structures.

*From a Facet.

Sucrose is obtained from sugar beets and sugar cane. Most sucrose in the United States is imported. Fructose tastes twice as sweet as sucrose. Using enzymes to make fructose from corn starch is less expensive than importing sucrose, but educating people to change recipes and to use fructose would be a long, difficult, and costly process.

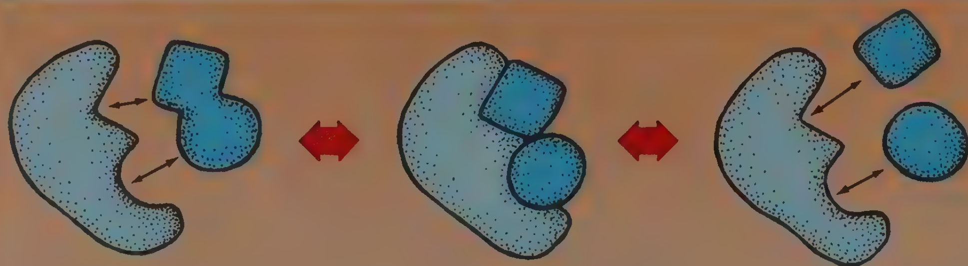
Ask students why it would not be profitable to wait for the third enzyme to work on more of the glucose molecules, making them into fructose. This enzyme catalyzes the reaction both ways, depending upon the concentration. In other words, when there is more glucose, it makes fructose; if more fructose, the enzyme converts fructose to glucose. Without outside factors, an equilibrium of fructose/glucose contains the highest amount of fructose obtainable. In living things enzyme-controlled reactions are often driven by other factors beyond the state of equilibrium.

Enzymes That Make Soft Drinks Sweet

Enzymes are used commercially in the making of soft drinks. Glucose, the most widely available sugar, is not sweet enough to satisfy human taste buds. Fructose, a different arrangement of the same atoms found in glucose, tastes twice as sweet as glucose. Until scientists found ways to obtain enzymes from bacteria, there was no economical way to make large quantities of fructose from glucose. Today enzymes are used to break down inexpensive corn starch into glucose and to change glucose to fructose.

The first enzyme, α-amylase, breaks apart the polysaccharide corn starch. This makes the thick corn syrup much thinner because the molecules which make up the solution are shorter. Next, the enzyme glucoamylase breaks apart the long chain of glucose molecules which make up corn starch. The fluid becomes a solution of glucose in water. The third enzyme, glucose isomerase, converts the glucose to fructose. This process is continued until there are about equal amounts of each in the solution.

The fructose-glucose solution can then be added directly to soft drinks or other foods. Each year the United States soft-drink industry saves over $1 billion by using sweeteners made from domestic corn rather than importing other forms of sugar.



of the enzyme and substrate is called the *enzyme-substrate complex.* While they are together, the enzyme breaks the substrate apart. The changed substrate is called the *product.* Notice that the enzyme is unchanged at the end. It has merely helped the reaction to take place.

❑ For most enzymes the process is reversible. In other words, the illustration can also be read from right to left. In that case the enzyme would put two substances together to form a larger product. Often it is the concentration of the substrate that determines whether the enzyme puts the substance together or takes it apart. If there is an abundance of the small molecules, the enzyme will put them together; if there are more of the large molecules, the enzyme will take them apart.

Enzymes are the essential keys to life. Every reaction a living thing carries on is catalyzed by an enzyme. Every organic substance that makes up an organism is manufactured by enzymes. The larger and more complex the structures of an organism are, the more enzymes it must be able to produce and the larger the quantity of each kind of enzyme it must have. But even the smallest organisms must be able to produce thousands of different enzymes and thousands of copies of each just to remain alive.

Review questions on next page.

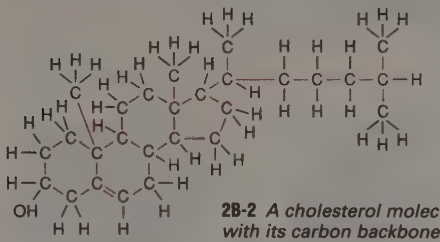
Answers–Review Questions 2B-1

1. (1) Contain carbon (usually in conjunction with hydrogen and oxygen); (2) function as structural compounds; (3) function as enzymes; (4) function in storage; (5) usually a product of biosynthesis (from living organisms)
2. Carbon
3. (1) Structure; (2) enzyme; (3) storage

Answers–Facet 2B-1

1. Enzymes are proteins; they are highly specific, may require energy, and may release energy as they function. Some require coenzymes; enzymes are affected by heat, pH, ion concentration, etc. They often work in series.
2. The processes carried on by cells are controlled by enzymes. Without enzymes the chemical reactions that a cell must carry on would require or give off too much energy or would happen too rapidly or too slowly for the living condition to continue.

bonds involve other carbon atoms in chains or rings, which form the backbone of most organic molecules. Sometimes a carbon atom will form two bonds with the same carbon atom to form a double bond. Occasionally two atoms will even form a triple bond. In the cholesterol molecule below, the carbon backbone has been drawn in red. The double-bonded carbon atoms have two lines drawn between them. Note the carbon rings and the carbon chain.



2B-2 *A cholesterol molecule with its carbon backbone in red*

Organic compounds perform various functions for living organisms and can be categorized as follows:

- *Structural:* those compounds that are used as building blocks of a cellular or extracellular structure;
- *Enzymatic:* those compounds that are **enzymes** or that help enzymes in their functions; and
- *Storage:* those compounds that store either energy, substances, or information for future use.

Many organic compounds perform combinations of these functions.

The large number and variety of organic compounds make grouping them difficult. They are often classified into four main groups: carbohydrates, lipids, proteins, and nucleic acids.

monosaccharide: mono- (Gk. MONOS, single) + -saccharide (L. SACCHARUM, sugar)

glucose: (Gk. GLUKUS, sweet)

galactose: galact- (Gk. GALAKT-, milk) + -ose (Fr. -OSE, carbohydrate or sugar)

fructose: fruct- (L. FRUCTUS, fruit) + -ose (sugar)

Do not have students memorize the structural formula for cholesterol or for any other compound diagrammed in this book. The structural formulas simply illustrate principles.

Visual 2B-1 is designed to be used at the end of each presentation of the various organic compounds. Display the empty chart and ask the students whether the compound is used in living things for structure, as an enzyme, or in storage. If it is used in storage, ask whether it stores materials, energy, or information. Briefly discuss each answer. Upon completion, the chart should have marks in the categories below.

Review Questions 2B-1

1. List several attributes of organic compounds which distinguish them from inorganic compounds.
2. What chemical element is found in all organic compounds?
3. List three functions an organic compound may have in living organisms.

Facet 2B-1: Enzymes-The Keys to Life, pages 59-60

1. List several characteristics of enzymes.
2. Why is it accurate to say that enzymes are essential to physical life?

Carbohydrates

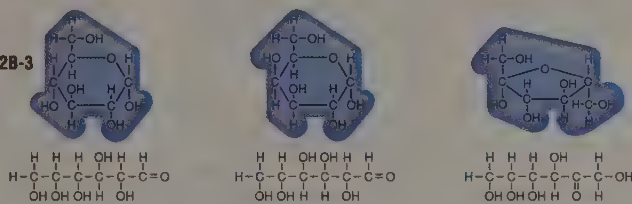
Carbohydrates (KAR boh HYE drates) are organic compounds that contain carbon, hydrogen, and oxygen. They have the same ratio of hydrogen to oxygen as water does: twice as many hydrogen atoms as oxygen atoms. Carbohydrates are both structural and energy storage compounds.

Simple sugars

The basic units of carbohydrates are **monosaccharides*** (MAHN nuh SAK uh RIDES), simple sugars. A monosaccharide may contain as few as 3 carbon atoms. The monosaccharides that contain 5 or 6 carbon atoms are most important as building blocks of other organic compounds. A common 5-carbon sugar is *ribose*, a component of nucleic acids.

Glucose* (a most common simple sugar manufactured by plants) is a 6-carbon sugar that is transported to the cells by the blood in humans. Two other simple 6-carbon sugars are important in biology: *galactose** and *fructose*.*

2B-3



glucose galactose fructose

Glucose is often called *dextrose* or *grape sugar.*

Note that all of these formulas are $C_6H_{12}O_6$. The difference is the arrangement of atoms within the molecules. Students should not memorize the arrangements.

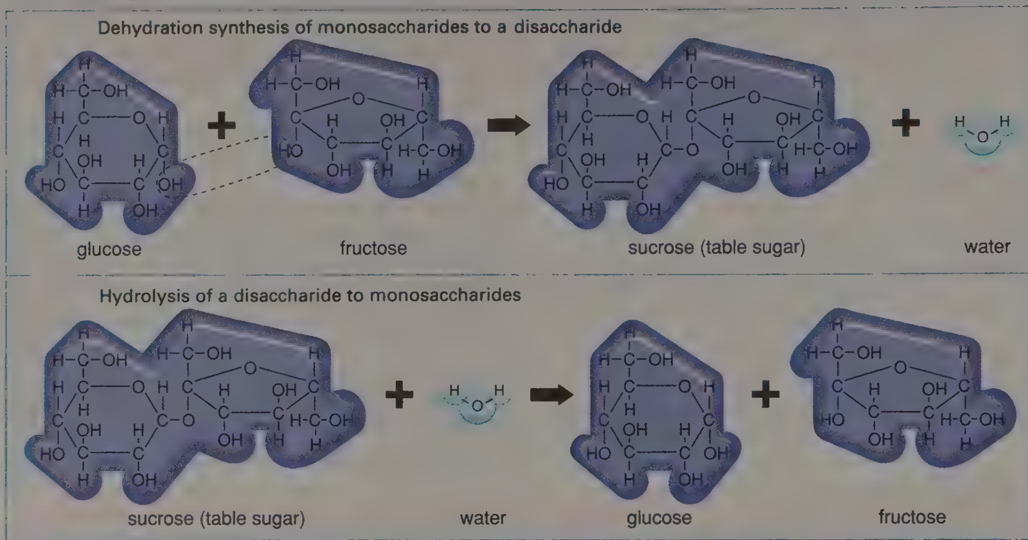
Visual 2B-1

The Functions of Organic Compounds

Organic Compounds	Functions: Structural	Functions: Enzymatic	Storage: Energy	Storage: Material	Storage: Information
Carbohydrates	✓		✓	✓	
Lipids	✓		✓	✓	
Proteins	✓	✓		✓	✓*
Nucleic Acids					✓

*Energy and materials can be stored in proteins, but they are poor storehouses compared to carbohydrates and lipids. It can also be argued that proteins (enzymes) have information and thus store it. The primary information-storage organic compounds are the nucleic acids.

2B-4 *Forming monosaccharides and disaccharides*



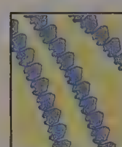
Monosaccharides can be joined together by enzymes to form a **disaccharide*** (dye SAK uh RIDE). In figure 2B-4 a glucose and a fructose molecule are combining by **dehydration* synthesis** (DEE hye DRAY shun ◊ SIN thuh sis). The glucose molecule loses a hydroxyl group (-OH) from one of its carbon atoms. The fructose gives up a hydrogen atom. The reaction gives off a water molecule and combines the glucose and fructose molecules to form the disaccharide **sucrose,*** the common sugar found in most foods and often called table sugar.

Because the process gives off a water molecule, it is a *dehydration* reaction. Because two substances are put together to form another substance, the reaction is called a *synthesis*. Two glucose molecules can combine by dehydration synthesis to form *maltose* (malt sugar); glucose and galactose form *lactose** (milk sugar).

When a cell needs the monosaccharides from which a disaccharide is made, enzymes will combine with the disaccharide and a water molecule. The two monosaccharides separate, the water molecule is broken down, and the hydrogen and hydroxyl group are attached to the appropriate carbon atoms of the monosaccharides. This process is termed **hydrolysis*** (hye DRAHL ih sis) because a large molecule is broken down by adding a water molecule.

Polysaccharides

A **polysaccharide*** (PAHL ee SAK uh RIDE) is a large, complex bonding of monosaccharides. Using specific enzymes, living things can build up or break down polysaccharides. Three types are particularly significant:



❑ **Starch** is one of the primary substances plants store as food. Corn starch and potato starch, as well as starches found in wheat, rice, and other grains, constitute the major source of food energy for humans.

❑ **Glycogen** is often called animal starch. The starches a person eats are broken down to simple sugars and, along with the other sugars in his diet, are then taken to the liver where they are made into glycogen for temporary storage. Glycogen is a branching chain of glucose molecules.

disaccharide: di-, diplo- (Gk. DI, two) + -saccharide (sugar)

dehydration: de- (L. DE, from) + -hydra- or -hydro- tion (Gk. HUDOR, water)

sucrose: sucr- (Fr. SUCRE, sugar) + -ose (sugar)

lactose: lact-, lacto- (L. LACT-, milk) + -ose (sugar)

hydrolysis: hydra- or hydro- (water) + -lysis (a loosening)

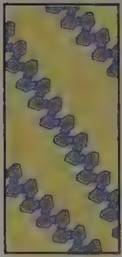
Glucose will play a major role in later discussions; it is suggested that students know the shape used to represent it in this book. Most of the sucrose added to foods is made by plants. Plant cells use an enzyme to convert glucose made by photosynthesis to fructose (see box, p. 60). Plant cells then use other enzymes to make the stable sugar sucrose by dehydration synthesis.

Sugar cane, sugar beets, and other plants are sources of sucrose.

Carbohydrates are structural and energy-storage substances. They also serve several specialized functions on cell membranes involved in regulating what substances enter the cell.

In the United States most of the refined starch comes from corn, while in Europe, most comes from potatoes.

Visual 2B-2 is a collection of the shapes of the various molecules used in this text. They are designed to be duplicated and cut out. These pieces can then be used on the overhead projector to illustrate various molecules and many of the processes discussed in the chapter. Using an overhead projector pen to indicate changes in the structure of the molecules can be helpful. Consider duplicating some of the shapes on heavy paper (or on standard paper attached to a heavy card stock) and then cutting the shapes out. These will cast shadows when used on the overhead. Without the structural formula in the molecule, students are better able to understand how the molecules combine to form other structures.



❑ **Cellulose** (SEL yuh LOHS) molecules are much larger than starch molecules. They are made of long chains of glucose molecules bonded in an alternating arrangement. The long cellulose molecules account for the strength of plant cell walls. Plant fibers that form cotton, wood, paper, and many other products contain large quantities of cellulose. Cellulose is nondigestible to most animals because they do not have the proper enzymes for breaking apart the bonds between its glucose molecules. The energy contained in the glucose molecules that make up cellulose is not directly available to animals. Cellulose is a primary part of the nondigestible portion of our diet called *bulk* or *roughage*. Certain bacteria, fungi, and protozoans, however, do produce enzymes for digesting cellulose.

polysaccharide: poly- (Gk. POLUS, many) + -saccharide (sugar)

lipids: (Gk. LIPOS, fat)

Cellulose constitutes 50% of woody tissues and over 90% of cotton fiber.

Bulk is necessary in the diet for proper movement of material in the digestive system.

Review Questions 2B-2

1. What substances make up carbohydrates? What characteristics do carbohydrates have?
2. Compare and contrast hydrolysis and dehydration synthesis.
3. List several monosaccharides, several disaccharides, and several polysaccharides.

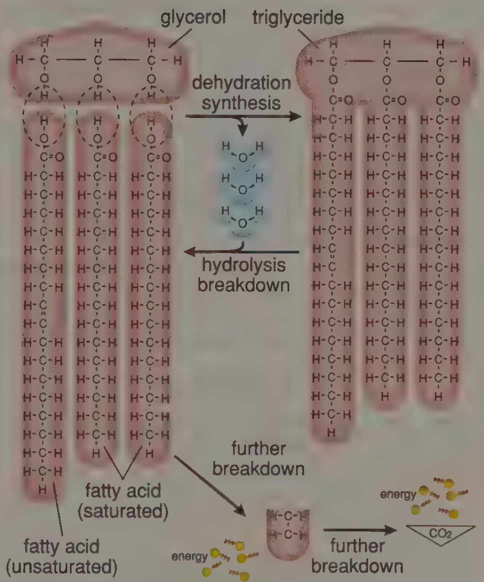
Lipids

Lipids* are a group of organic substances which are only slightly soluble in water but are very soluble in organic solvents such as alcohol, ether, acetone, and chloroform. Lipids are most often structural, but they also store energy. A gram of lipid contains much more potential energy for organisms than does a gram of carbohydrate. Because lipids occupy less space than starches, animals store their excess energy as lipids. Plants, however, add to their size by storing starches.

Fats

The most abundant lipids are **fats**, and two fatlike substances, oils and waxes. Fat molecules consist of three *fatty acid molecules* bonded to the 3 carbon atoms of a 3-carbon alcohol called *glycerol* (glycerin). As each fatty acid molecule bonds to the glycerol molecule, a water molecule is released. Fat molecules are formed by a *dehydration synthesis* reaction. Fats can, of course, be broken apart by *hydrolysis* with proper enzymes. Fats are generally found in animal tissues and in dairy products.

The fatty acids of living things are chains usually composed of 14-18 carbon atoms. Fatty acid molecules can be broken into many 2-carbon molecule pieces. Each of these molecules may eventually release usable cellular energy, making fatty acids a good energy source.



2B-5 *The formation of a fat (triglyceride) from fatty acids and glycerol. A comparison of saturated and unsaturated fatty acids.*

Many lipids are composed of C, H, and O. Their H to O ratio, however, is never 2:1. Lipids often have P and sometimes other elements in them.

A gram of fat has twice as many calories as a gram of carbohydrate.

During digestion the enzymes in the small intestine aid fat molecules in reacting with water, producing fatty acids and glycerol.

Answers–Review Questions 2B-2

1. Carbohydrates have twice as many H atoms as O atoms. They are organic compounds containing C, H, and O. They serve as both structural and energy-storage compounds.
2. Both processes involve a water molecule and other molecules. In dehydration synthesis (2B-4, top), 2 molecules are combined, giving off a water molecule in the process. In hydrolysis, however, the 1 molecule is broken apart by the addition of a water molecule (2B-4, bottom).
3. **(1)** Monosaccharides–glucose, galactose, ribose, fructose; **(2)** disaccharides–lactose, sucrose, maltose; **(3)** polysaccharides–cellulose, glycogen, starch

hydrophilic: hydro- (water) + -philic (Gk. PHILEIN, to love)

hydrophobic: hydro- (water) + -phobic (Gk. PHOBOS, fear)

Steroids are a hormonal form of sterols. Steroids are discussed on pages 605-6.

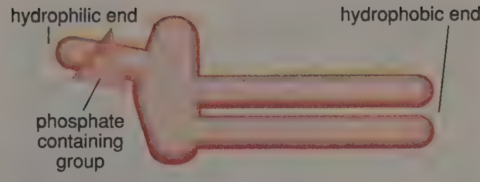
Cholesterol is a natural component of all human cells. The body makes cholesterol. The cholesterol one eats, however, is not the same cholesterol found in the body. Consumed cholesterol is digested. The link between eaten cholesterol and the amount of cholesterol in the blood is unclear. Improving one's diet (e.g., fewer lipids, less salt) and increasing one's exercise do seem to help lower one's blood cholesterol level.

If each of the carbon atoms in a fatty acid molecule (except the end ones) has 2 hydrogens attached to it, the fatty acid is *saturated.* If one or more of the carbon atoms are double bonded, not permitting as many hydrogen atoms to be attached to the carbon chain, the fatty acid is *unsaturated.* The double-bonded carbons of an unsaturated fat require additional enzymes to break apart. The controversy regarding the nutritional value of saturated and unsaturated fats results from this difference in the number of hydrogen atoms that the fatty acids of a fat molecule contain.

Lipids that are liquid at room temperature are called *oils.* Corn oil, olive oil, peanut oil, and coconut oil are examples of vegetable oils. *Waxes* result when several fatty acids join to alcohols made of long chains of carbon. Waxes commonly cover plant leaves and stems. Waxes also make up the honeycomb.

Phospholipids and sterols

A **phospholipid** (FAHS foh LIP id) is composed of 2 fatty acid molecules attached to a glycerol molecule. The third carbon atom of the glycerol molecule has a phosphate-containing group attached to it. Most phospholipids also have other



2B-6 *A phospholipid*

substances attached to them. *Lecithin* (LES uh thin), a common phospholipid, is a major component of cellular membranes.

Phospholipids, like all fatty acids, have a *hydrophilic** (HYE druh FIL ik) end and a *hydrophobic** (HYE druh FOH bik) end. If a phospholipid is dropped on the surface of water, the molecules will align themselves with the hydrophilic ends in the water and the hydrophobic ends away from the water. This characteristic is important in the forming of cell membranes, which is discussed later.

Sterols are made of 4 carbon rings and a side chain of carbons. They often combine with other substances to form hormones and other compounds. *Cholesterol,* a common sterol, is found along with phospholipids in the membranes of animals and human cells.

Review Questions 2B-3

1. What substances make up a lipid? What characteristics do lipids have?
2. List several lipids.

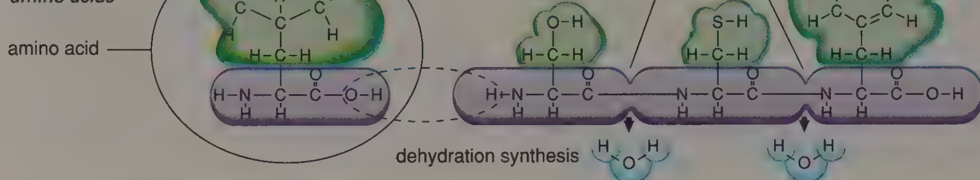
Visual 2B-3 can be used as an outline for presentation of the material or as a review. It is best used for review.

Students should not memorize the structural formula; however, they should note that the purple section is the same in all amino acids.

Proteins

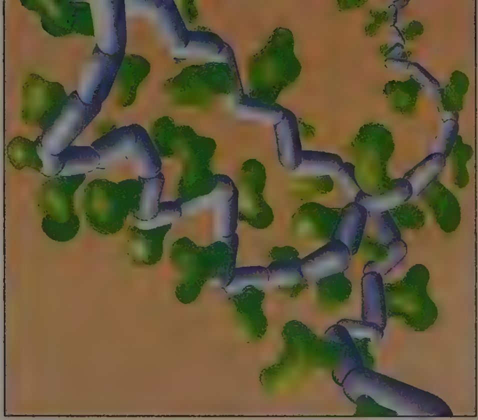
The glucose in one plant is exactly the same as the glucose in every other plant and in every animal. No matter where you find it, a glucose molecule is a glucose molecule. The same is true of all carbohydrates and lipids (fats) as well. The amounts may vary, but the carbohydrates and lipids in an organism are just like the same carbohydrates or lipids in any other organism. Proteins, however, are different.

2B-7 *The formation of a polypeptide chain of amino acids*



Answers–Review Questions 2B-3

1. Lipids are made up of C, H, and O (often in the form of fatty acids and glycerol). Lipids are only slightly soluble (generally insoluble) in water but soluble in organic solvents such as alcohol, acetone, ether, and chloroform. They most often serve as structural compounds, but they also store energy efficiently.
2. Fats, oils (corn oil, peanut oil), waxes, phospholipids (lecithin), sterols (cholesterol)



2B-6 *The twisting and bonding of a polypeptide chain of amino acids gives it a three dimensional shape, which is characteristic of proteins.*

Although there is overlapping of the types of proteins in organisms, many proteins are different in each group and even in each individual organism. For example, human insulin, a protein that helps in food metabolism, is virtually identical to the insulin found in animals. Human hair protein, on the other hand, is different from the protein found in animal hair. Yet despite the fact that one person's hair proteins are similar to another's, they are not identical. Proteins, it may be said, are the things that make you unique.

Proteins come in a wide variety and are used either as enzymes or as structural building blocks. Some are very small, but some are large enough to be seen under high-powered microscopes.

Proteins consist primarily of carbon, hydrogen, oxygen, and nitrogen; but they sometimes include phosphorus, sulfur, and a few other elements. The basic building blocks of a protein are **amino** (uh MEE NOH) **acids.** There are about 20 different amino acids. An amino acid contains an amino group (-NH_2) and a carboxyl group (-COOH), both attached to a carbon. Different side groups (some simple, others complex) attach to the carbon of the amino acid. As few as 50 or as many as several thousand amino acids can line up in a specific sequence to make a protein.

When 2 amino acids line up and the proper enzymes are present, dehydration synthesis occurs, removing a water molecule and forming a *peptide** (PEP TIDE) *bond.* A peptide bond is one which links the carboxyl and the amino groups of two amino acids. A protein, then, begins as a **polypeptide*** (PAHL lee PEP TIDE) **chain** of amino acids.

When the proper sequence of amino acids is arranged, the chain twists and then folds back upon itself. Certain amino acids bond together in a specific pattern that is determined by the sequence of the acids. The polypeptide chain of amino acids now has a 3-dimensional arrangement. It is this shape that forms the active sites of enzyme proteins.

If some of the amino acids are out of sequence, the shape of the protein molecule may be altered. Should this change of shape affect the active site of an enzyme, the enzyme may not react properly with the substrate. Heat, radiation, ion concentrations, and other factors can also affect the bonding of amino acids to other parts of the amino acid chain. When the bonds break between the amino acids that give the protein its three-dimensional shape, the shape of the protein molecule may change. If this change affects the active site of an enzyme, it may no longer function as an enzyme. The ability of a protein to fit in as a cellular building block may also be affected by these changes in shape.

Proteins often work together with other proteins or other substances. Enzyme proteins may require coenzymes in order to function. Some proteins combine with lipids, carbohydrates, or even other proteins to form a structural component. Hemoglobin, the red pigment in human blood which carries oxygen, is made of 4 polypeptide chains. Attached to each chain is an iron-containing heme group. Many hormones are lipids joined with proteins.

peptide: (Gk. PEPTEIN, to digest)

polypeptide: poly- (many) + -peptide (to digest)

The peptide bond occurs between the C of the carboxyl group and the N of the amino group (see diagram, p. 64).

Proteins are structural or enzymatic. The body stores substances and energy in proteins, but they are rarely used this way. Only in unusual circumstances, such as starvation, will one obtain substances or energy from proteins.

The reason the number of amino acids is not exact is that some odd amino acids are found only in certain organisms. Some are very rare. Others are common to all forms of life.

Some of the information on enzymes in the Facet (pp. 59-60) is illustrated and explained by the information presented here. Tie the two together in the lecture.

Material on proteins may seem abstract to students, but it is crucial to their later understanding of genetics and even evolutionary concepts. Present the points here, but realize that there will be reinforcement of the concepts later.

Review Questions 2B-4

1. Describe the relationship between amino acids and proteins.
2. What gives a protein molecule its 3-dimensional shape?

Answers–Review Questions 2B-4

1. Amino acids are the basic units of proteins; the identity and sequence of the amino acids determine the protein that is formed.
2. Proper amino acid sequence causes the peptide chain to fold and bend upon itself due to interaction between the amino acids. The polypeptides gain a three-dimensional shape which results in the protein's conformation and activity.

nucleus: nucle- or nucleo- (L. NUX, nut or kernel, *hence,* central part)

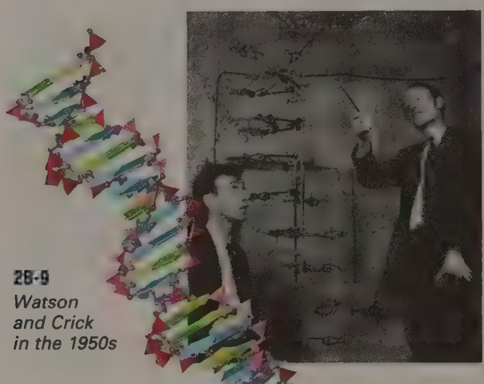
There are several good visuals to help in teaching the nucleic acids. Use them first, and then use this picture for review.

Nucleic Acids

Although scientists have long known that proteins are different in various organisms, they did not discover until just before World War I that **nucleic** (noo KLEE ik) **acids,** not proteins, are the material of heredity. In other words, to transmit its characteristics to another cell, a cell must pass nucleic acids to that cell.

Nucleic acids, found in the nucleus* (NOO klee us), direct the activities of a cell by guiding the formation of both structural and enzymatic proteins. Because they contain the information necessary for the manufacture of the organism's proteins, nucleic acids determine its characteristics. In other words, nucleic acids form *genes.* The way the nucleic acids direct protein manufacture and the exact method of transmitting this information to the next generation of cells are important concepts for later chapters. At this point we shall examine what nucleic acids are.

DNA, deoxyribonucleic (dee AHK see RYE boh noo KLEE ik) acid is the primary nucleic acid in most organisms. About the time of World War II, scientists analyzed the components of DNA but were confused about their exact arrangement. To determine how DNA functions, it was necessary to form a working model of its components. In 1953, James D. Watson, an American biologist, and F. H. C. Crick, a British biophysicist, assembled information about DNA's components. Using information obtained from X-rays of DNA, they created a DNA model. Watson and Crick received a Nobel prize in 1962 for their accomplishment. Although since then it has been slightly modified, the basic model is still consistent with all the information we have about DNA.



2B-9
Watson and Crick in the 1950s

The structure of DNA

Watson and Crick's model is a double helix, or spiral, consisting of two strands attached at regular intervals. Visualizing a flexible ladder, twisted, gives a good idea of what it looks like.

For study purposes we shall untwist the DNA molecule and examine its component parts. DNA is a double chain of **nucleotides.** A nucleotide (NOO klee uh TIDE) has three components:

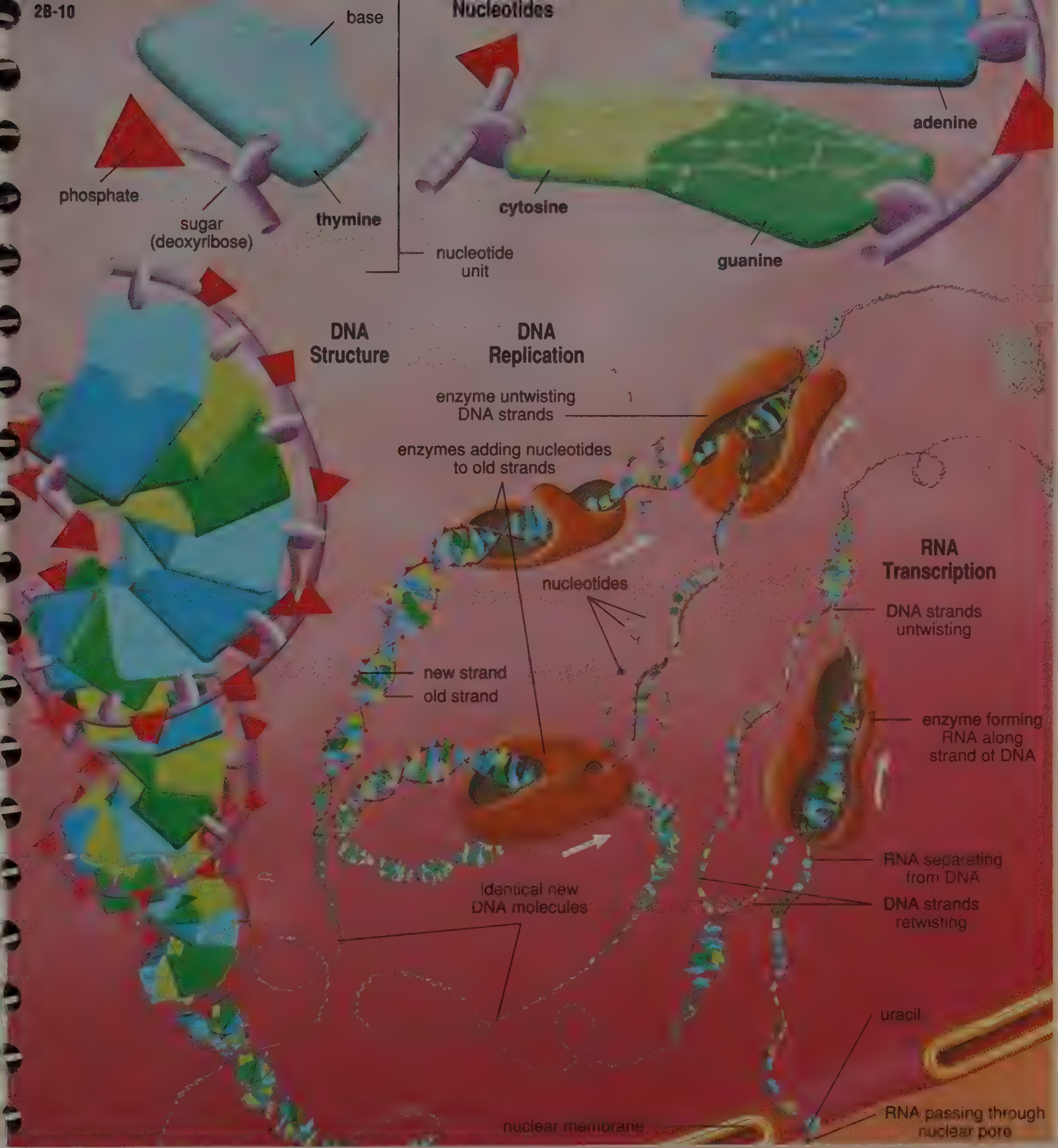
- *sugar* (the sugar in DNA is the 5-carbon sugar deoxyribose),
- *phosphate* (the phosphate in a nucleotide is a small molecule made of phosphorus and oxygen atoms), and a
- *base* (each nucleotide will have one of these four bases: *adenine, thymine, guanine,* or *cytosine*).

The nucleotides line up so that the sugars and phosphates form one long side piece of the ladder, and the bases point off to one side, forming one half of each rung (step) of the ladder. The other half of the ladder is likewise formed by nucleotides.

Figure 2B-10 illustrates a typical DNA molecule. Note carefully the bases. Each adenine is bonded with a thymine by 2 hydrogen bonds, and each cytosine is bonded with a guanine by 3 hydrogen bonds. When there is a thymine on one side, there is an adenine on the other; and when there is a guanine on one side, there is a cytosine on the other.

DNA replication

The sequence of the bases in the DNA molecule can be compared to the sequence of letters in this sentence. In one order the letters make words and have meaning. In another order they may make different words and mean something else. In other arrangements the letters may make words in another language, or they may be senseless. The sequence of bases in DNA is the code which, through a series of steps, directs the sequence of



Hydrogen bonding is illustrated by the dotted lines in the drawing. These weak bonds occur between a partially positive-charged H atom and an atom that has a partial negative charge. The electrostatic attraction (see p. 45 teaching note) that results is much weaker than either ionic or covalent bonding and can be easily broken by certain enzymes, allowing the DNA molecule to separate.

See additional information about teaching this material in the Notes for this chapter.

Answers–Review Questions 2B-5 *(p. 68)*

1. **(1)** DNA (deoxyribonucleic acid); **(2)** RNA (ribonucleic acid)
2. A DNA molecule is a twisted double chain of nucleotides, each nucleotide being made up of a sugar, a phosphate, and a base (either adenine, thymine, guanine, or cytosine). The nucleotides line up to form a ''ladderlike'' structure, with the adenine on one side of the ladder binding with thymine on the other and the guanine on one side binding with cytosine on the other.
3. To replicate, DNA does not require a mold from another source; it is capable

replication: re- (L. RE-, back) + -plication (PLICARE, to fold)

transcription: trans- (L. TRANS, across) + -scription (SCRIBERE, to write)

amino acids in the protein molecules that the cell produces.

The message encoded within the sequence of bases in DNA must be copied *exactly* so that it can be given to the next generation of cells. A DNA molecule must be able to make a duplicate of itself that is exact, even to the *sequence* of bases. If the base sequence is not correct, an improper protein–or possibly no protein at all–may be manufactured.

DNA uses itself as a direct blueprint in duplicating itself. Visualize this process as the opening of a zipper. An enzyme moves down the DNA molecule, breaking the hydrogen bonds which are holding the sides of the DNA molecule together. The two sides do not close like a zipper, however. Rather, loose nucleotides replace the missing side for each half of the molecule. There are then two identical molecules of DNA. The sequence of bases is complete and is exactly the same in both strands of DNA. Producing two new DNA molecules from an old one is called **replication*** (REP lih KAY shun). The enzyme systems necessary for this operation are vast and intricate.

RNA–another nucleic acid

RNA, ribonucleic (RYE boh noo KLEE ik) acid, is the basic nucleic acid for very few organisms, but it is important for all. Through RNA the "message" of DNA's base sequence is delivered, read, and converted to a chain of amino acids, thus producing protein. However, in RNA the sugar is ribose, which has one more oxygen atom than DNA's deoxyribose. In RNA the base *uracil* replaces the thymine found in DNA.

RNA is formed by DNA. As an area of the DNA molecule uncoils, the two sides separate. Nucleotides line up on one side, but rather than becoming a new DNA molecule, the new chain of nucleotides separates from the DNA strand. This separated chain of nucleotides is an RNA molecule. This process of transferring the complementary DNA base sequence to a molecule of RNA is called **transcription.***

Biological Terms

organic
biosynthesis
vitalism

Carbohydrates
carbohydrate
monosaccharide
glucose
disaccharide
dehydration synthesis
sucrose
hydrolysis
polysaccharide
starch
glycogen
cellulose

Lipids
lipid
fat
phospholipid

Proteins
protein
amino acid
polypeptide chain

Nucleic Acids
nucleic acid
DNA (deoxyribonucleic acid)
nucleotide
replication
RNA (ribonucleic acid)
transcription

Facet
enzyme
coenzyme

Answers begin on page 67.

Review Questions 2B-5

1. What are the two primary nucleic acids?
2. Describe the structure of a DNA molecule.
3. What is unique about a DNA molecule?
4. What is unique about an RNA molecule?
5. List the four main groups of organic compounds.

Thought Questions

1. If a scientist were to assemble a living thing from nonliving parts, would this disprove the Bible? Why or why not?
2. Enzymes are the most important of organic chemicals. Support or disprove this statement.
3. Carbohydrates are carbohydrates, and lipids are lipids. But nucleic acids and proteins they manufacture truly constitute the organism. Support or disprove these statements.

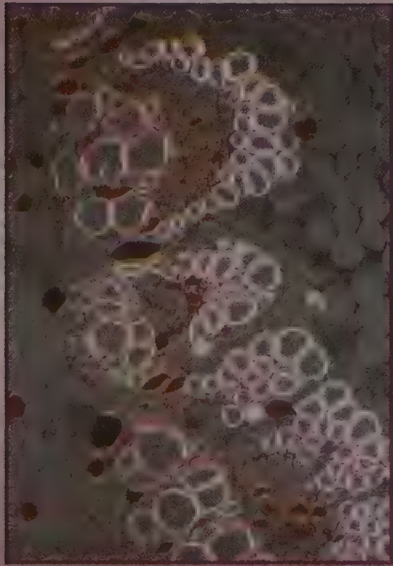
of serving as a direct blueprint for making copies of itself.

4. In RNA the base thymine is replaced with uracil, the sugar is ribose (which has one more oxygen than the deoxyribose found in DNA), and it is a single rather than a double chain of nucleotides.
5. (1) Carbohydrates; (2) lipids; (3) proteins; (4) nucleic acids

Answers–Thought Questions

1. It would not disprove the Bible. Scientists have already formed a DNA molecule that replicated, but they did not form the smaller molecules that were used to produce the DNA. In other words, scientists may be able to fabricate life from preexisting, nonliving materials. Even if this is ever done, it would not prove the Bible wrong. Even if life were observed occurring spontaneously from nothing, the Bible would not be proven wrong. The Bible is stating historic truth as it describes God's creative acts. Scripture does not specifically state that there will be no more creation of life or that God must directly perform creation of all living things. The focus of Genesis 1 and 2 is the creation of matter, from which life is made.
2. Enzymes are essential for life, and a case could be made for their being the most important chemicals; however, it is difficult to decide which organic compounds are most important, since life is possible only when all are present.
3. It is true that the nucleic acids and their proteins are the substances that make organisms different; however, any organism is the result of all its molecules' functioning properly. Carbohydrates and lipids are needed for many important cellular functions. Without them life would not exist.

INTRODUCTION TO CELLS
CYTOLOGY PART I



THREE

cytology: cyto- (Gk. KUTOS, hollow or cell) + -logy, -logi, or -logo (Gk. LOGOS, word, *hence,* the study of)

cells: (L. CELLAE, chambers)

protoplasm: proto- (Gk. PROTOS, first) + -plasm (PLASSEIN, to mold)

Time Frame
3A: 2-3 periods
3B: 1-2 periods

Laboratory Activities
3A–*Basic Cytology* involves learning to make a wet mount and observing various cells (cork, onion, cheek) and staining the cells to see the nucleus.

3B–*Cellular Structure and Processes* involves staining to observe some cellular structures (banana leucoplasts, *Elodea* chloroplasts) and to observe cytoplasmic streaming and plasmolysis of *Elodea* cells.

3A–The Cellular Structure

Cytology* (sye TAHL uh jee), the study of cells, can be traced back 300 years to the English scientist Robert Hooke. In 1665 he published *Micrographia,* a report of his use of simple compound microscopes capable of magnifying only about thirty times. He described his observation of a thin slice of cork: the neat rows of little boxes reminded him of rows of cells in a prison or a monastery; he therefore named what he was looking at "cells." Although Hooke saw only the dead, empty walls of those "boxes," and we now know that those boxes have vastly different sizes, shapes, and arrangements in other organisms, they are still called *cells.**

At first the walls or boundaries of cells were of interest, primarily because they were almost all that man could see. As microscopes and microtechniques improved, however, scientists recognized the contents of the cell as the primary substances of living organisms. In 1840 J. E. Purkinje first used the term **protoplasm*** (PROH tuh PLAZ um) to refer to the entire substance of cells.

3–Cytology Part I: Introduction to Cells

About this time of the school year, parents, administrators, or colleagues may comment, "I was not taught this when I was in school." This can mean one of two things: "I am glad the students are getting up-to-date material," or "This new-fangled stuff should not be taught." Usually the intention is obvious.

The students have probably been tolerant until now. "Once we get past the introduction," they have been telling themselves, "we will get to the good stuff like cutting up things and hearing about the birds and the bees" (both meanings intentional). The prospect of learning this material about cells is discouraging; it is not what they were expecting. Both the discouraged students and the "teach-what-I-was-taught-forty-years-ago" philosophers require justification of this material. Do not falter. Be very straightforward in its defense. The teaching of this material to Christian teens is more than justifiable.

Forty years ago the structure of DNA was but a glimmer in the minds of Watson and Crick. The electron microscope was a novelty that produced some interesting pictures of unfamiliar things. Ideas about photosynthesis had changed little since van Helmont and Priestly. Krebs was working on his citric acid cycle. It is not surprising that forty years ago much of the material in this chapter was not in even the most up-to-date high school biology course. It had just appeared in the periodicals read in graduate-school courses. Current opposition to this material, however, is usually due to either a fear of the material or a failure to understand its importance.

The cell is the common denominator of life. What man knows about it is useful in understanding the how and why of every living thing. Ecological studies, agricultural studies, and all other biological studies are

nucleus: (central part)

absorption: ab- (L. AB, away from) + -sorption (SORBERE, to suck)

digestion: di- (apart) + -gestion (GERERE, to carry)

excretion: ex- (out) + -cretion (L. CERNERE, to separate)

egestion: e- (out) + -gestion (L. GERERE, to carry)

Visual 3A-1 is a summary of chart 3A-2, *Cellular Functions and Processes,* and can be used as visual reinforcement during the teaching of this material.

Students should know about Robert Hooke and his contribution to biology, the naming of cells. Point out that *cell,* however, is almost a misnomer. It is not the dead box that Hooke saw but what it contains that is significant. Today *cell* refers to the protoplasm and the plasma membrane which surrounds it. The cell walls are considered to be outside the cell even though they are essential to the existence of many cells.

Hooke was "the curator of instruments" for the Royal Society of London. There are no pictures of Hooke drawn during his lifetime. Only a few descriptions of his appearance remain today.

Students should learn the definition of each of these terms. They appear in the Biological Terms section at the end of the chapter.

Other cell secretions include hormones, oils of the skin, digestive enzymes, and the cell wall and slime coat.

Humans accomplish each of these processes. Ask the class for an example of each in the human body. Point out that humans have many (often large) structures for accomplishing these distinct functions. A unicellular organism and many of the cells in a multicellular organism perform the counterparts of these processes within the cells.

3A-1 *In 1665 Robert Hook used the microscope illustrated to draw cork cells (inset).*

Although it had been recognized before, in 1833 Robert Brown set apart the *nucleus** as a special structure found in all cells. His and other studies attached significance to the role of nuclei during cellular division and to the nuclei of egg and sperm cells.

The year 1838 brought a startling and daring statement from a German botanist, Matthias Schleiden (SHLY den). After observing much botanical material under the microscope, he said that all plants are composed of cells. Most scientists who did not use microscopes ridiculed him. But the next year Theodore Schwann (SHVAHN), a German zoologist, made a similar statement about animals.

The Cell Theory

After 200 years of investigation, the **cell theory** was formulated in the late 1800s. Continued research in cytology in the past 100 years, including recent discoveries, have confirmed the scientific accuracy of the three basic principles of the cell theory.

- Cells are the units that make up all living things.
- Cells are the units that carry on the functions of all living things.
- Cells come from preexisting cells.

Today cytology is divided into several overlapping areas of study, which include the structures in cells, the molecules which make up those structures, and the functions of those structures and molecules. Someone has suggested that more has been learned about cells in the past 10 years than in the 200 years before the cell theory was formulated. Let us examine the three principles of the cell theory.

3A-2 **Cellular Functions and Processes**

Nutrition	Absorption:*	transport of dissolved substances into cells to serve as building blocks or energy sources
	Digestion:*	enzymatic breakdown of substances to secure building materials or energy
Internal Functions	Synthesis:	putting together organic compounds from smaller units obtained from digestion, absorption, or some other synthesis reaction in the cell. Synthesis results in a cell's growth, secretion, or replacing worn out cellular parts.
	Respiration:	breakdown of food (usually glucose) with the release of energy
	Movement:	movement of the cell itself (*locomotion*) or the *internal movement*, the movement of substances and structures inside the cell
	Irritability:	ability to respond to external factors that affect the operations of the cell; that is, the response or reaction of the cell to its environment
Releasing Materials	Excretion:*	removing soluble waste materials from cells
	Egestion:*	eliminating nonsoluble, nondigestible wastes from cells
	Secretion:	synthesizing and releasing materials from a cell
Continuing Existence	Homeostasis:	maintaining a steady state in a cell, thus permitting its existence
	Reproduction:	formation of new cells

basically a study of how an environment affects cells. The scientific bases for creationism and the biological bases for rejecting evolution are based on an understanding of cells. Major decisions regarding scientific advances (from test-tube babies and clones to organ transplants, euthanasia, and genetic engineering) can be made wisely only with an understanding of cellular biology. Because these issues are probably among the major decisions that current high school students will need to make during their lifetime, it is imperative that Christian students learn this type of material. Omitting or skimming over it because it is modern, difficult, or unpopular among the students would be unfair to the Christian cause.

A good education forty years ago prepared young men and women to live in the world at that time. The fact that those same men and women are successful today does not mean that current students will do equally well on yesterday's knowledge.

That which is basic to an understanding of some major area of knowledge should be taught. Any knowledgeable person will agree that basic cytology is essential groundwork for any current biological understanding. Cytology is not a new field of study; it is the foundation of modern biology.

Cells—units of living things

The size of most organisms does not indicate the size of its cells but rather the number of its cells. For example, although a mouse and an elephant have cells of about the same size, their quantity of cells is different.

Not all of the organism is made of cells. Those parts of an organism that are not composed of cells are made of materials that cells manufacture. An insect's body covering is a *secretion* of some of the cells of the insect. It is interesting also that much of the materials composing our bones are cellular secretions.

Cells—functions of living things

Cells are responsible for all the functions of any living thing. Because the things cells do are so various and overlapping, it is impossible to easily describe those functions. The cellular functions given in Table 3A-2 are more a list of the processes of life than a list of what cells do. Not all cells perform all these functions. In a complex organism like the human body, some cells perform a few of these functions almost to the exclusion of other functions.

Cells of an organism are *specialized* for particular functions. Most multicellular organisms have

Levels of Cellular Organization

Many organisms consist of only one cell. These organisms are called **unicellular.** Bacteria, as well as many protozoans, algae, and fungi, are unicellular. **Multicellular** organisms are made up of many cells. Some algae and fungi, as well as all plants and animals, are multicellular.

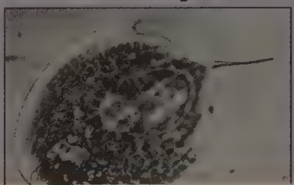
Some organisms are **colonial.** A colonial organism is a collection of similar cells living together. Except for certain reproductive cells, each of these similar cells could, if separated from the others, carry on the processes of any cell in the organism. Colonial organisms include many algae and fungi. A mushroom, for example, is a colonial, highly structured organism. Evolutionists often call unicellular and colonial organisms the "first" or "early" organisms. These terms are not accurate, however, since all life was created at the same time.

Most multicellular organisms are made up of **tissues**—similar cells that are grouped together and perform similar functions. Tissue cells normally depend upon other tissues to supply some of their needs. In other words, various tissues carry on different tasks to keep the organism alive. The muscle cells of our body compose tissues whose primary function is movement. Muscles, however, depend upon the blood tissue to bring them oxygen, the tissues of the digestive tract to prepare food for their ready use, and the nervous tissues to regulate when and how much they contract. Tissues are specialized to perform certain functions and cannot exist under normal conditions by themselves. Scientists have been able, however, to grow tissues in special laboratory conditions.

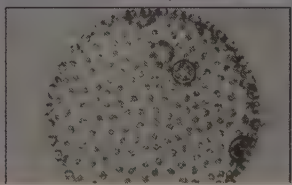
Many multicellular organisms have **organs.** Tissues grouped together to perform a specific function form an organ. For example, the stomach includes tissues that strengthen it, cover it, compose its glands, make it churn, and perform other functions. All these different tissues work together to digest food, the major purpose of the stomach. Yet no single tissue that is part of the stomach is capable of digesting food by itself.

Organs in many organisms are arranged into **systems**—groups of organs working together to accomplish life functions. Your brain, eyes, ears, and taste buds, and the nerves that connect these structures are organs. These and a few other organs together compose the nervous system, which enables you to sense and respond to your environment, coordinate your activities, think, remember, and perform other related functions.

unicellular organism



colonial organism



tissue

Visual 3A-2 is a teaching outline of the levels of cellular organization.

The material in this box is basic and should not be omitted.

Define each term and give examples. Discuss the fact that cellular division of labor and specialization are possible only in organisms consisting of tissues. Of course, in unicellular and colonial organisms, there is division of labor within the cells.

3A—The Cellular Structure

Notes—Chapter 3A

This cell anatomy section includes many names and structures. Because most students have little difficulty memorizing the concrete, this chapter can become more of a memory exercise than a learning experience. When lecturing, stress the physiology to counterbalance the students' natural bent to reduce everything to "the ten things I have to know for the test." Be careful not to let the teaching become a dry summary of the chapter's content, but teach the lighter and more "where-I-live" type of material presented in the chapter.

If the scientific educational background of the students has been good, they will be familiar with cells, cytoplasm, the nucleus, and many organelles. In this study of cytology, the students should gain an appreciation of the diversity and complexity needed for the vast variety of cells which make up the living things on this planet.

Objectives—Chapter 3A

- ❑ List and describe the concepts of cell theory.
- ❑ Describe cellular membranes.
- ❑ List and define the processes carried on by cells.
- ❑ List the levels of cellular organization of living things.
- ❑ Explain the division of labor concept at both the cellular and organismic level.
- ❑ Describe the various boundaries of cells.
- ❑ List and describe the function of the basic cellular organelles.
- ❑ Describe the function of the cell's nucleus.

eucaryotic: eu- (Gk. EUS, good) + -caryotic (KARUOTIS, with a central part)

cytoplasmic: cyto- (cell) + -plasm (to mold)

organelle: (L. ORGANUM, organ)

been designed with cellular *division of labor*. Each tissue or group of cells performs only a few of the processes of a living organism, but somewhere in the organism other cells are accomplishing the other functions.

In order for the organism to be alive, collectively the cells must be accomplishing *all* these functions. That they do so is not as surprising as the fact that unicellular and colonial organisms accomplish *all* these functions in one cell. Unicellular and colonial organisms are occasionally called the "simple organisms." Considering that in the space of a single cell these organisms do all the same basic functions that many organisms accomplish with billions of cells, the term "simple" seems inappropriate.

Cells—reproduction of living things

For most cells the biosynthesis of materials results in maintenance and growth of the cell. The science fiction cell "that grew so large it swallowed New York," however, is not possible. When most cells reach a particular size, they either slow down their synthesis of materials, secrete certain synthesized materials, or divide. The built-in control of a cell (the DNA) can control only so much; therefore, cell division after a limited amount of growth is essential for most cells.

Cells reproduce by dividing. Cellular division results in a new organism (if the organism is unicellular), more cells in the same organism, or a sex cell, like an egg or sperm. Processes of cellular reproduction are discussed in Chapter 5.

Review Questions 3A-1

1. List the three concepts of the cell theory.
2. Give the differences between a colony and a tissue.
3. Give two examples of (a) organs in the human body and (b) systems in the human body.
4. List ten of the primary functions of cells.

Structures of the Cell

The etymologies of *eucaryotic* and *procaryotic* show that evolutionary thinking was entrenched in science when these terms were coined. They say subtly that the "simpler" organization of procaryotic cells is an early step in evolution, which is not true (see p. 243). Although it reflects evolutionary thinking, this term is the accepted name of this group of cells. We could not communicate with others about them if we tried to rename these cellular groups.

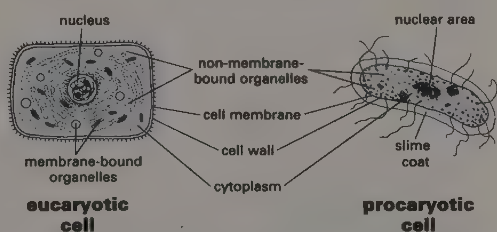
Cells are so diverse in their functions and structures that finding a "typical" cell is impossible. There appear to be only a few different types of cellular structures, but each of these structures has a great variety of forms in various cells. Cytologists regularly discover new attributes of cellular structures. As they have learned more about cellular biology, some concepts of cell structure and function have changed. The materials presented here are generalizations of the concepts accepted as true by most cytologists today. In the next few years, as more information is discovered, some concepts will change.

The parts of a cell can be put into the following three categories:

- *Boundaries*, which include the plasma membrane, and cellular coverings like the cell wall, capsules, and sheaths;
- *Cytoplasm*, which includes the cytoplasmic matrix and organelles; and
- *Nucleus*, which includes the nuclear envelope, chromatin material (DNA and other substances), nucleolus, and nuclear matrix.

Two types of cells

Cells are easily divided into two groups. **Eucaryotic*** (yoo KEHR ee AHT ik) cells, the first group, are those which have a true nucleus with a set of membranes around it and also have specialized structures called *cytoplasmic organelles** (OR guh NELZ), which accomplish the cell's



3A-3 *A comparison of a procaryotic and a eucaryotic cell*

They should also begin to appreciate the delicate and complex inner workings of cellular structures needed to maintain life. Teach with these goals in mind, not with the idea of getting through a list of cellular structures.

There are four boxes in Chapter 3A. The first two, *Levels of Cellular Organization* and *The Membranes Found in Cells*, should be covered by all students. They are basic to understanding the chapter and to other aspects of biology. The last two boxes, *Plant Cell Walls* and *Cytoskeletons*, are supplemental. They are not essential to understand later sections of the book.

Answers—Review Questions 3A-1

1. (1) Cells are the units of living things. (2) Cells are the units that carry on the functions of all living things. (3) Cells come from preexisting cells.

*2. A colony is a collection of cells living together, each cell capable of carrying on life processes independently and of forming another colony. A tissue is made up of similar cells grouped together to perform a similar function; these cells, however, normally depend upon other tissues to supply some of their metabolic needs.

*3. (a) Organs: heart, liver; (b) systems: digestive, respiratory

4. See chart 3A-2 on p. 70.

*From a box.

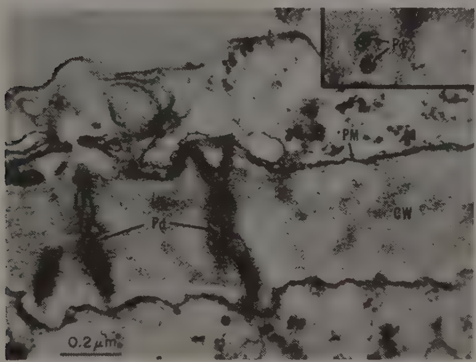
functions. Organelles with membranes around them are called *membrane-bound organelles*. Others lack membranes and are called *non-membrane-bound organelles*. Plants, animals, and several other groups have eucaryotic cells.

The various structures of eucaryotic cells will be discussed individually in the next sections of this chapter. Note figures 3A-5, a typical animal cell, and 3A-9, a typical plant cell. Remember, there is no such thing as a *typical* cell. These diagrams are included to help you visualize the structures of eucaryotic cells as you read about them. Returning often to them will be helpful.

Bacteria, blue-green algae, and some similar organisms are composed of **procaryotic** (proh KEHR ee AHT ik) cells, the second group. These cells lack a true nucleus and have only non-membrane-bound organelles. Procaryotic organisms and their cellular structures will be discussed in greater detail in Chapter 9.

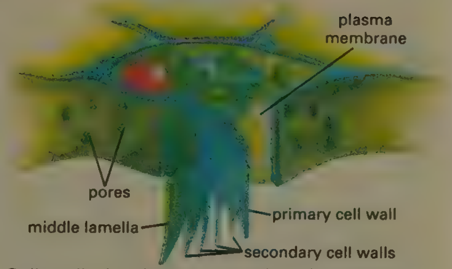
Cell boundaries

Technically the outer boundary of the cell which is still a part of the cell is the *plasma membrane*. Many cells, however, have structures outside of their plasma membranes which are not actually part of the cell. We will consider cellular *capsules*, *sheaths*, *coats*, and *cell walls* as part of the boundaries of a cell even though they are really outside the cell.



3A-4 *An electron micrograph of a cell wall* **(CW)** *showing plasma membrane* **(PM)** *and connective structures passing through the pores* **(Pd)** *(27,400X)*

Plant Cell Walls



Cell walls in plants, as well as in many other organisms, are made primarily of cellulose. The *primary cell wall* is made when the cell is first forming and has not reached its full size. A plant's primary cell wall is made of about 20% to 30% cellulose fibers randomly arranged, about 70% water, and a variable amount of pectin–a jellylike substance which solidifies cellulose. It is found in abundance in some fruits and serves as the solidifying agent in jelly. The softness and flexibility afforded by the loosely bonded, random arrangement of cellulose fibers allows some cellular growth.

When the plant cell reaches maturity, it forms a *secondary cell wall* inside the primary cell wall but outside the cell membrane. The secondary cell wall has a higher percentage of cellulose, and the fibers are arranged in layers of almost parallel rows, each layer going a different direction. Additional pectin, hardening substances such as *lignin,* and a decreased amount of water make the secondary cell walls more rigid than the primary wall. Plant fibers (such as cotton) and wood are predominantly cell walls. These various cells demonstrate the strength of their cellular structures.

Cells that have cell walls have a barrier between the environment and their plasma membranes. In order for materials to enter and leave the cell, it is necessary for the cell wall to have *pores.*

Plasma membranes

Every cell, whether procaryotic or eucaryotic, has a **plasma membrane** (or *cell membrane*) which serves as the outermost boundary of the cell itself. The plasma membrane is the only thing that separates some cells from their environment. The cells of your body are like this. For your individual cells, though, other body cells are insuring

The material in this box is supplemental and may be omitted if time is limited. Note that cell walls are secreted (one of the cellular processes).

Pectin (and occasionally lignin) is found in several commercial products which can be added to homemade jelly and other foods to cause them to gel. Sure-Jell and Certo are two common products of this type.

In most plants the cells are adjacent, and between the cell walls of neighboring cells is a layer called the *middle lamella,* which primarily contains pectins.

The cell walls of other organisms often do not contain cellulose. For example, bacterial cell walls are mostly lipids, polysaccharides, sugars, and proteins. Cell walls of some algae and a few plants contain silicon, the substance from which glass is made.

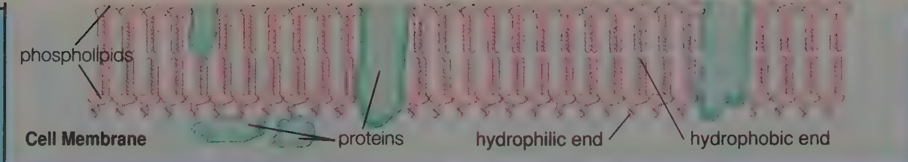
Pages 239-40 discuss the cellular structure of bacteria–typical procaryotes. Emphasize that the rest of this chapter deals with eucaryotes.

The material presented in this box is crucial to understanding cellular structure and function and should not be omitted. The term **plasma membrane** is listed in the Biological Terms section at the end of the chapter. It is suggested that students also know *cellular membrane, internal cellular membrane, micelle, lipid bilayer,* and *membrane-bound enzymes.* Be sure to inform students if they are required to know these terms for testing purposes.

The old concept of a unit membrane made of layers of protein, fat, fat, protein has been replaced as more careful observations have revealed that cellular membranes have vastly different structures, depending on which cell and organelles are observed. That the membrane is a lipid bilayer with associated proteins seems to be the only characteristic that holds true for all cellular membranes.

Possible demonstration: Place a few drops of cooking oil on the surface of a dish of water (a Petri dish works well). Try adding food coloring to the water to make the oil more visible. Use a toothpick to break the lipid layer and watch how it reforms.

Cooking oil does not usually contain phospholipids; so the students are not observing a true lipid bilayer, but the idea is the same. Stress that there are two fluids here, and the oil is serving as a membrane to the water. (E.g., Will the water evaporate as rapidly if there is a layer of oil on it? *[no]* Can dissolved materials in the air get into the water? *[not without passing through the oil first]* If the materials in the air cannot pass through the oil, they will not get into the water.)



The Membranes Found in Cells

Would it be confusing to say that a cell is a fluid that contains fluids for structure, that it is encased in a fluid, and that it is surrounded by fluids? It might, unless you understand something about the unusual fluid membranes found in and around all cells.

Cellular membranes are the membranes found in and around cells. Cellular membranes can be put into the following two groups:

- **The plasma membrane** The plasma membrane, sometimes called the *cell membrane*, surrounds the cell's cytoplasm, separating the cell from its environment. (Be careful not to confuse cellular membranes [all the membranes in a cell] and the specific cellular membrane called the cell membrane.)
- **The internal cellular membranes** The internal cellular membranes form many of the structures in the cytoplasm.

Although cellular membranes may differ greatly within a single cell and even more greatly between cells, all of the membranes found in cells have some common characteristics. One thing that cellular membranes have in common is that they are composed of lipids. In fact, it is the unusual properties of lipids in water that give cellular membranes their "fluid" characteristic. For example, normally, lipid molecules do not dissolve in water. Thus if a drop of lipid is placed in water it will form a thin film on the surface of the water. This film of oil on water is an example of a *fluid* membrane.

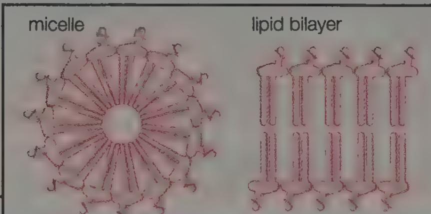
Normally, cellular membranes are made of phospholipids (see page 64), which have hydrophobic and hydrophilic ends. In water, phospholipids form a little ball, called a *micelle*, or a *lipid bilayer*. The hydrophilic ends in these structures point outward and the hydrophobic ends point inward. One of the differences in cellular membranes is the combinations of various phospholipids and other lipids (such as cholesterol, which is found in all animal and human cellular membranes). Some lipids have longer fatty acid tails, and some have bent fatty acids which help to make the membrane stronger.

All cellular membranes also have proteins. In the past, various "sandwiches" of proteins and fats have been proposed to describe the structure of cellular membranes. Today most scientists agree that the various proteins that make up different cell membranes are found scattered through the lipid bilayer.

Different proteins also give various membranes distinct properties. Some of the proteins permit various substances through the membranes and some prohibit others from passing. Other membrane proteins are enzymes. These are called *membrane-bound enzymes*, and many important cellular processes happen along these membranes. Some proteins are structural in that they add strength or rigidness to the membrane. Some of these proteins have polysaccharides or other substances attached to them and give the membrane other properties.

Cellular membranes are *self assemblable.* If the molecules of such a membrane are physically separated, they will realign themselves as a membrane because of the hydrophilic and hydrophobic properties of the lipids and their attraction for the proteins. Some of the more complex enzyme-containing membranes take longer to reassemble than the simpler membranes.

If you were to take a fine glass needle and puncture the plasma membrane, does all the cytoplasm flow out of the cell? No. Disrupting the line-up of a portion of the fluid lipids and proteins that form the plasma membrane is a temporary problem. The membrane is self-assemblable. In short order the molecules reassemble into a membrane around the fluid cytoplasm, separating it from its fluid surroundings. See, it is not so confusing.



that the environment in which the individual cells exist has the correct temperature, pH, food supply, and every other condition suitable for maintaining life. Cells that do not have similar protection must have other forms of protection.

Cell walls and capsules

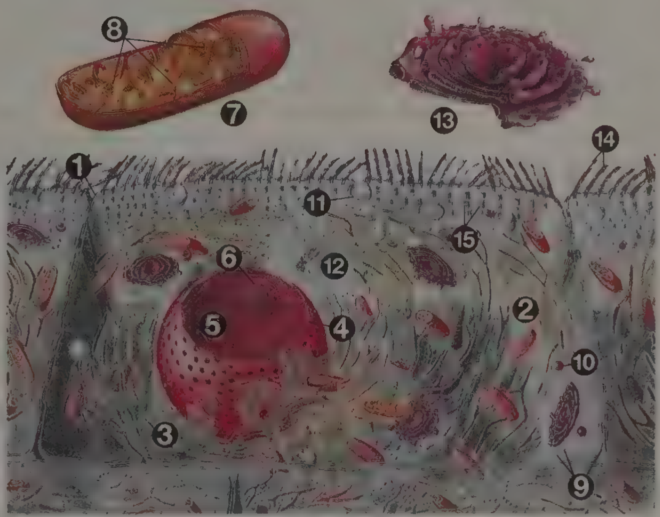
Although every cell has a plasma membrane, not every cell has a **cell wall.** Procaryotes, plants, algae, fungi, and many protozoans have some type of cell wall, but animal cells do not. The cell wall is a rigid or nearly rigid structure surrounding the cell. It is manufactured by the cell and assembled outside the plasma membrane. Since a cell wall is organic material that has been *secreted* by the cell, a cell wall is not alive, but it is still a necessary structure for those cells that have one.

Many unicellular or colonial organisms have a **capsule** or **sheath** in addition to (or occasionally in place of) a cell wall. Sometimes the capsule is called a *slime coat.* Capsules are made of cellular secretions (often polysaccharides and lipids) of varying thickness and are made without definite structures. Capsules give clusters of bacteria and algae their shiny appearance and slimy feel. They protect the cell because material entering it must first either dissolve the capsule or pass through it.

Visual 3A-3 is a simplified cell drawing which can be used as a diagrammatic outline for teaching cellular structures. Consider labeling (and possibly using pens to color) each cellular structure as it is discussed. Remove the diagram and teach about the organelle. Then place the diagram back on the overhead and teach the next organelle.

Although the colors in this drawing have been chosen somewhat arbitrarily (animal cells are normally colorless), they will be used for the same structures or processes later in the text.

3A-5



Structures in a Typical Animal Cell

1. plasma membrane
2. endoplasmic reticulum, smooth
3. endoplasmic reticulum, rough
4. nuclear envelope
5. chromatin material, nucleoplasm
6. nucleolus
7. mitochondria
8. cristae
9. ribosome
10. lysosome
11. vacuole
12. centrioles and microtubules
13. Golgi body
14. cilia
15. basal body

Review Questions 3A-2

1. List the three basic parts of a cell.
2. Compare the structures of procaryotic cells and eucaryotic cells.
3. What are the two main kinds of cellular membranes?
4. What is the difference between a cell membrane and a cellular membrane?
5. What are the two main components of cellular membranes? What characteristics do each of these components give to the cell membrane they make?
6. What property of phospholipids permits them to form micelles and lipid bilayers?
7. Describe the structure of a cellular membrane.
8. Compare a plasma membrane with a cell wall.

Answers–Review Questions 3A-2

1. **(1)** Boundaries (cell membrane, wall capsule, and other coatings); **(2)** cytoplasm (matrix and organelles); **(3)** nucleus (nuclear envelope, chromatin, nucleolus, and nuclear matrix)
2. Procaryotic cells lack a true nucleus and have only non-membrane-bound organelles. Eucaryotic cells have a true nucleus, a set of membranes around the nucleus, and specialized structures called cytoplasmic organelles, which may be membrane bound or non-membrane bound.

*3. **(1)** Plasma membrane; **(2)** internal cellular membrane

*4. A cell membrane is a kind of cellular membrane. A cell membrane is a membrane that surrounds a cell. Internal cellular membranes are also cellular membranes.

*5. **(1)** Lipids, which are not water soluble and often have hydrophobic and hydrophilic ends, permit the self-assembling property of cellular membranes; **(2)** proteins, which are either structural or enzymatic

*6. Phospholipids have water-loving (hydrophilic) and water-hating (hydrophobic) ends.

*7. Cellular membranes are fluid membranes made of lipids and proteins and are found inside cells.

8. The plasma membrane is made of lipids and proteins, is self-assembling, and is part of all cells. The cell wall, usually made of secreted cellulose, is outside the cell and is found only around plant and a few other forms of cells. The plasma membrane is a fluid structure; the cell wall is rigid.

*From a box.

endoplasmic: endo- (in) + -plasmic (to mold)

reticulum: (L. RETE, net)

Note some of the powers used to obtain these photomicrographs.

See colloid description (p. 56).

Suggested method of teaching the organelles: Draw a large, colorful, progressive diagram of a cell on the chalkboard or overhead projector. It will look somewhat like the eucaryotic cell in 3A-5 (p. 75) when it is finished. Ask students, "What would you find inside a cell?" When they suggest something from their reading, draw it in, describe it, and ask for a phrase to describe its function. Relate functions to cellular processes. Have students look at the electron micrographs on these pages when discussing a cellular part that is illustrated.

A cell may contain from 12 to more than 1,000 mitochondria. They are abundant near the surface of cells that secrete substances as well as in muscle and parts of nerve cells. Animal cells generally have more mitochondria than plant cells.

ER is more like a hollow tube in many plant cells.

Studies have cast doubts on the role of the ER in cellular support and its attachment to the plasma membrane.

Cytoplasm

The term **cytoplasm** (SYE tuh PLAZ uhm) refers to all the material inside the plasma membrane, excluding the nucleus. The cytoplasm appears as a semisolid, yet fluid, substance with small granules suspended in it. Even high magnification with the light microscope reveals only the largest of these granules clearly.

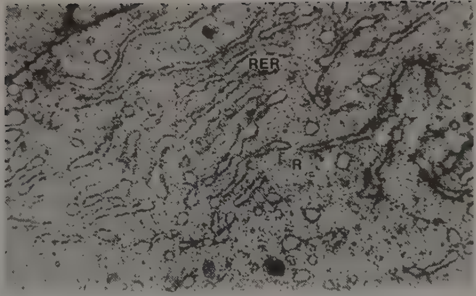
The **cytoplasmic matrix** is the watery substance in which the granules are suspended. It is a colloid made of proteins, fats, carbohydrates, ions, and small compounds in combinations that differ from cell type to cell type. It is a reversible phase colloid that is capable of *cytoplasmic streaming*, a flowing inside the boundaries of the cell. This movement involves the changing of the matrix from sol to gel and back again. Cytoplasmic streaming rearranges the cell's contents for particular purposes. In some plant cells, for example, cytoplasmic streaming moves the structures responsible for catching light and making sugar. The structures are moved in a circular pattern and thus all of them are exposed to the area of the cell that receives the most direct light.

Cytoplasmic organelles are structures in the cytoplasm which can be compared to the organs of the human body: each accomplishes a different function, and each must function properly in order to maintain a healthy condition. A survey of some of the primary cytoplasmic organelles and their functions follows. Some will be discussed in greater detail in later chapters.

Ribosomes and endoplasmic reticulum

A **ribosome** is a non-membrane-bound organelle found in both procaryotic and eucaryotic cells. These small units are actually strands of RNA with proteins attached to them. Some of these proteins constitute the enzyme system necessary for protein synthesis.

With the invention of the electron microscope, cytologists found that the cytoplasmic matrix of many cells has folds of cellular membranes running through it. These folded membranes are called **endoplasmic*** (EN doh PLAZ mik) **reticulum*** (rih TIK yuh lum), abbreviated ER.

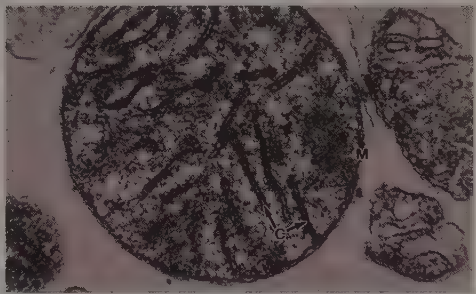


3A-6 *An electron micrograph showing rough endoplasmic reticulum* **(RER)** *and ribosomes* **(R)** *(27,400X)*

In some cells the ER is continuous with the membranes around the nucleus. Some ER is dotted with ribosomes and is called *rough ER*. Endoplasmic reticulum lacking ribosomes is called *smooth ER*. ER helps to give the cytoplasm a flexible yet structured shape. The ER also has membrane-bound enzymes and thereby functions in the synthesis of complex compounds. Much rough ER is found in cells that secrete protein-containing materials. Cells that secrete sterols contain much smooth ER. ER also serves as a channel for the movement of substances.

Mitochondria

Nicknamed "the powerhouse of the cell," these typically bean-shaped organelles are responsible for the respiration of sugars to release *usable* cellular energy. **Mitochondria** (MYE tuh KAHN dree uh) are double-membrane-bound, with the inner membrane having folds called *cristae*. On the inner surface of the inner membrane, which



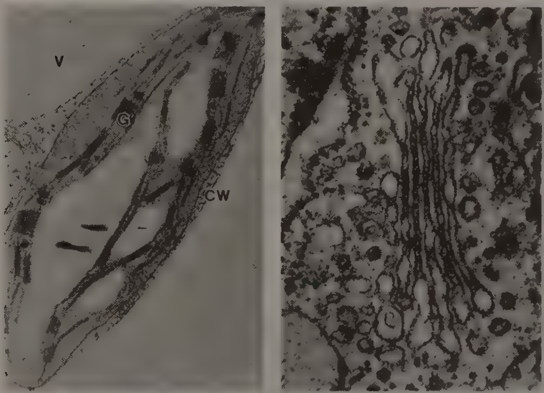
3A-7 *An electron micrograph showing a mitochondrium in cross section. The double membrane* **(M)** *and cristae* **(C)** *are visible. (27,500X)*

is considerably lengthened by the cristae, are many membrane-bound enzymes necessary for the process of *cellular respiration*.

The *mitochondrial matrix*–the fluid which is in the mitochondria–contains other enzymes for respiration. Depending upon the energy demands, mitochondria may be large and numerous with many cristae, as in muscle cells, or they may be small and relatively few with only a few cristae.

Plastids

Plastids are membrane-bound organelles found in the cells of plants, algae, and a few other organisms, but not in animals. Plastids are either *leucoplasts** (LOO kuh plasts), colorless structures used as storehouses, or *chromoplasts** (KROH muh PLASTS), structures that contain pigments and usually serve in synthesis processes. Leucoplasts are found in the fleshy storage areas of plants. Potatoes, root crops, and many fruits have leucoplasts containing starches and, occasionally, oils. Chromoplasts containing red, orange, yellow, and other pigments are often found



3A-8 *Electron micrographs of a chloroplast (left) showing grana* **(G)**, *the cell wall* **(CW)**, *and a vacuole* **(V)** *(8400X); and of a Golgi body (right) (27,400x)*

The most common and best-known chromoplast is the **chloroplast,*** a green, sugar-manufacturing organelle. Chloroplasts are various sizes and shapes in various organisms. Some chloroplasts are cup-shaped and are nearly as large as the cells that hold them. Others are flat or even spiral-shaped. The most common chloroplasts are round or football-shaped.

Chloroplasts contain a fluid called *stroma* and flattened sacs called *thylakoids** (THYE luh koydz). A stack of thylakoids, which resembles a stack of coins, is a **granum**. The membranes of the grana hold the green pigment *chlorophyll*, which catches light energy and uses it to start the synthesis of sugar. The making of sugar is completed in the stroma.

Golgi bodies

In 1898, Camillo Golgi (GOLE jee) first described a cellular structure which has since been found in one form or another in almost all eucaryotic cells. The **Golgi body** (or Golgi apparatus) is important in the synthesis of complex polysaccharides. In the flat, often curved *saccules** (SAK yoolz) of the Golgi body, complex polysaccharides, lipids, and proteins are processed. These substances are then sealed in small sacs whose membranes appear to be made by pinching off the membrane of the saccule.

Most cells that secrete materials have many Golgi bodies, and the secretions can be traced to these sacs and the Golgi body. The cellulose and polysaccharides found in cell walls and capsules, for example, are assembled in the Golgi bodies.

Lysosomes

Most often when an organelle is seen, its function is discovered only after additional investigation. Exactly the opposite was the case for the **lysosome** (LYE so SOHM). Enzymes capable of digesting proteins were known to exist in cells, but scientists speculated that they could not be free in the cytoplasmic matrix, or they would digest parts of the cell itself. Careful investigation revealed the existence of small, membrane-bound organelles named lysosomes which contained these enzymes.

Normally lysosomal enzymes digest invading substances or large food substances. These enzymes help in breaking down complex structures and preparing the materials for reuse, but occasionally they destroy old or useless cellular structures. For example, lysosomes function in the *absorption* of a tadpole's tail.

leucoplast: leuco- (Gk. LEUKOS, white or clear) + -plast (to mold)

thylakoids: (Gk. THYLAKOS, a sack)

chromoplast: chromo- or chroma- (color) + -plast (to mold)

saccule: (L. SACCUS, a bag)

chloroplast: chloro- (Gk. KHLOROS, greenish yellow) + -plast (to mold)

At first there was a great deal of controversy over the existence of the Golgi body, for it could be seen only after complex staining operations. Some cytologists believed it was an *artifact*–the result of the cell's dying and of the preparations for microscopic reviewing–rather than an actual structure.

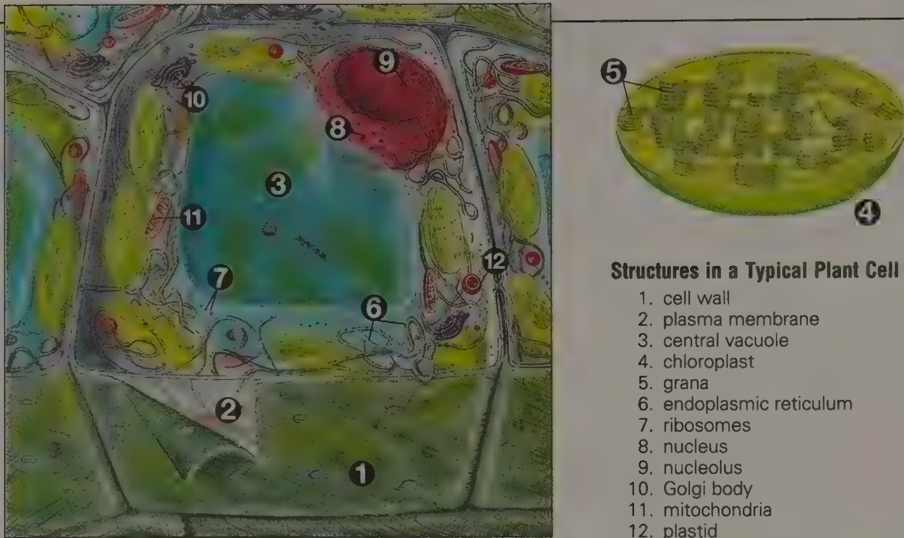
Some authorities suggest that the Golgi bodies found in a cell are actually connected and are all part of one large Golgi body.

At one time lysosomes were called suicide sacs because certain stimuli seemed to cause the cell to commit suicide by releasing the lysosomal enzymes which digested the cell. Actually, as the cell dies, the membrane which holds the lysosomal enzymes falls apart, causing protoplasm destruction. The process of cellular "remodeling" using lysosomes is sometimes called autophagy (discussed on p. 110).

vacuole: (L. VACUUS, empty)

vesicle: (L. VESICULA, little bladder)

phagocytosis: phago- (Gk. PHAGEIN, to eat) + -cyto- or -cytosis (cell)



Structures in a Typical Plant Cell

1. cell wall
2. plasma membrane
3. central vacuole
4. chloroplast
5. grana
6. endoplasmic reticulum
7. ribosomes
8. nucleus
9. nucleolus
10. Golgi body
11. mitochondria
12. plastid

3A-9

Students often find vacuoles and vesicles confusing. Cover them carefully. Point out the cellular processes accomplished by the various types.

Vacuoles and vesicles

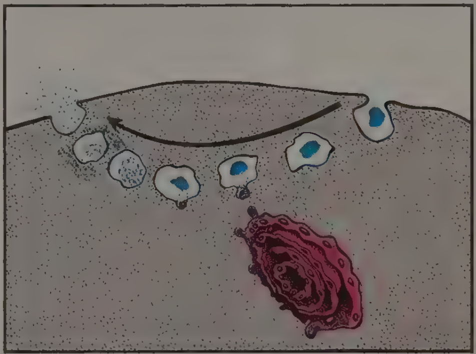
Vacuoles* (VAK yoo ohlz) can be compared to various household containers–different boxes, bags, and jars which have in common only the fact that they hold something. A vacuole is a membrane-bound sac which contains food, water, wastes, or other materials. A vesicle* (VES ih kul) is a small vacuole, but there are no distinctly defined size differences between vacuoles and vesicles. The best way to learn about vacuoles and vesicles is to examine some of the more common and important types.

The entering of materials into a cell can be called *endocytosis. Phagocytosis* forms food vacuoles (phagosomes), and *pinocytosis* forms pinocytolic vesicles.

❑ **Phagocytic vacuole** When certain cells contact solid food that is too large to absorb, they engulf it. The cytoplasm flows around the food. As the plasma membranes meet, they fuse, leaving the substance in a *food vacuole*. This process, called **phagocytosis*** (FAHJ uh sye TOH sis), has been described as cellular eating. In the case of phagocytic vacuoles, the *vacuolar membrane* was originally a part of the plasma membrane. Amebas and white blood cells carry on phagocytosis.

❑ **Food vacuole** Food vacuoles are formed by phagocytosis or other processes and serve as sites of cellular **digestion.** Lysosomes fuse with the vacuolar membrane, releasing their digestive enzymes into the food vacuole. The enzymes break down the food into substances which will pass through the vacuolar membrane into the cytoplasm.

❑ **Waste vacuole** After the lysosomal enzymes have completed their task, the nondigestible materials remain in a waste vacuole (residual body).



3A-10 *Cellular digestion. A food vacuole is formed. A Golgi-apparatus-formed lysosome fuses with the vacuole. The food is digested and absorbed into the cytoplasm. The wastes are then egested.*

Cytoskeletons

In the past biologists thought of the cytoplasm as a soup in which the chunks of meat and vegetables were the organelles and the broth was the cytoplasmic matrix. Although this may have been a good comparison, today biologists realize that cytoplasm requires a more complex structure than soup does.

Eucaryotic cells have been demonstrated to have a **cytoskeleton.** A cytoskeleton is made of proteins arranged as one of several structures. Two of the most common are the following:

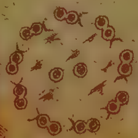
- **Microfilaments*** are tiny flexible strands. In many cells the microfilaments form a branching internal network through the cytoplasm. In plant cells the microfilaments are arranged in patterns that direct the motion of organelles during *cytoplasmic streaming.* Often microfilaments contain *actin,* a protein involved in contraction. (Your muscle cells, for example, contain large quantities of actin microfilaments.)
- **Microtubules*** are proteins arranged into a tubular shape. These protein units are able to assemble and disassemble rapidly, making the microtubule longer or shorter. Microtubules just inside the plasma membrane help to give shape to many cells. In growing plant cells microtubules probably help to arrange the cellulose strands as they are deposited in the cell wall.

A number of organelles are made of microtubules joined and arranged into particular configurations. A basal body, for example, has 9 sets of 3 joined microtubules arranged in a circle with other proteins, causing a cross section of this structure to look like a pinwheel. Basal bodies are attached to each other by microfilaments which are believed to coordinate the movements of multiple flagella or cilia.

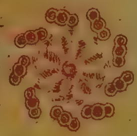
Each cilium or flagellum attached to the basal body usually has 9 sets of 2 microtubules arranged around a separated pair of single microtubules. From each pair of microtubules, reaching toward the next pair, are tiny arms made of the protein *dynein.* Dynein is able to bend and grab protein molecules in the next microtubule. As the dynein pulls on the proteins, the microtubules slide along each other, bending the flagellum or cilium.

Another organelle which is made of microtubules is the centriole. Centrioles have the same microtubule pattern as the basal bodies and are found in pairs positioned at right angles to each other just outside the nucleus of animal and human cells. As part of cell division, a cluster of microtubules forms around the centrioles. These microtubules look like a star and are called the *aster.** During cell division the microtubules of the aster play significant roles in moving the chromosomes.

The micrograph above shows a group of microtubules.
A cross section of a microtubule (right).
A model of a microtubule (below) illustrates the spiral arrangement of proteins.



The microtubule arrangement in flagella (c.s.).



A wheel arrangement of microtubules in a basal body (c.s.).

A diagram showing the bent and unbent characteristic of microtubules in a cilium

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microfilament: micro- (small) + -filament (L. FILUM, thread)

microtubule: micro- (small) + -tubule (L. TUBULE, tube)

aster: (Gk. ASTER, star)

This box presents detailed material and should be covered by advanced classes or advanced students. An average class can deal with the material, but it may require time better spent on other topics. This box presents that the cytoplasm has structure and that microtubules compose cilia and flagella and help with their coordinated movement.

The terms **cytoskeleton, microfilaments,** and **microtubules** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

It has been demonstrated that centrioles are involved in the formation of flagella and cilia. The centriole then remains with the structure as its basal body.

More information about centrioles, asters, and microtubules is found on pages 114-16.

Autoradiography (see p. 40) has been used to trace substances in the Golgi bodies and saccules.

Basal bodies are also illustrated but not labeled in the student text (p. 75).

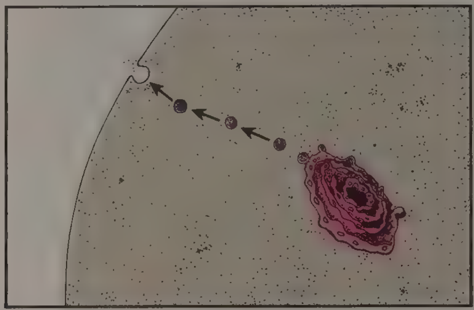
pinocytosis: pino- (Gk. PINEIN, to drink) + -cyto- or -cytosis (cell)

turgor: (L. TURGERE, to be swollen)

centriole: (L. CENTRUM, center)

Cytoplamic streaming moves the waste vacuoles to the plasma membrane where they fuse with it, releasing the nondigested insoluble wastes. The release of such wastes is called *egestion.*

❑ **Secretion vesicle** These vesicles are usually formed by the endoplasmic reticulum or Golgi body. They take the materials made by these structures to the plasma membrane. When the vesicle membrane and plasma membrane unite,



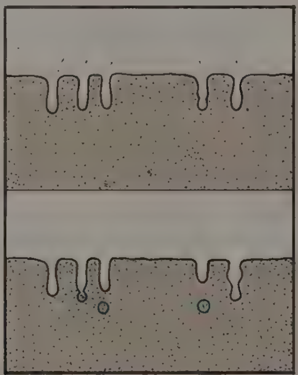
3A-11 *Secretion. A secretion vesicle formed by a Golgi-apparatus migrates to the plasma membrane and releases materials from the cell.*

The release of materials from a cell as egestion or secretion can be called *exocytosis.*

the material is *secreted.* Many secreted substances, including human hormones and the cellulose for cell walls, are released by secretion vesicles.

❑ **Pinocytic vesicle** If phagocytosis is cellular eating, **pinocytosis*** (PIN uh sye TOH sis) is cellular drinking. Some cells form tiny pockets in their cell membranes when they confront molecules too large to be absorbed. The tip is pinched, sealing the molecules in a fluid-filled vesicle.

3A-12 *Pinocytosis. Small substances collect in pockets of the cell membrane, which then pinch off to become vesicles.*



❑ **Central vacuole** Found in most plant and algal cells, this large vacuole is filled with water. Because of a high concentration of solutes in the fluid of the vacuole, water from outside the cell moves into the vacuole by osmosis. An internal pressure is then exerted on the vacuolar membrane, which in turn pushes on the cytoplasm, which then pushes against the cell wall. This cellular fullness because of water pressure in the central vacuole is called **turgor*** (TUR gur) **pressure.** The difference between crisp and wilted lettuce is the result of the plant cells being turgid (crisp) or lacking turgor (wilted).

❑ **Contractile vacuole** Many unicellular organisms that exist in water environments do not have cell walls. These cells, it seems, should burst since water molecules quickly come through the plasma membrane to equalize the concentration difference between the cytoplasm and the water outside. But under normal circumstances the cell collects these water molecules in contractile vacuoles. The contractile vacuoles, after reaching a certain size, fuse with the plasma membrane and release the water.

Centrioles, flagella, and cilia

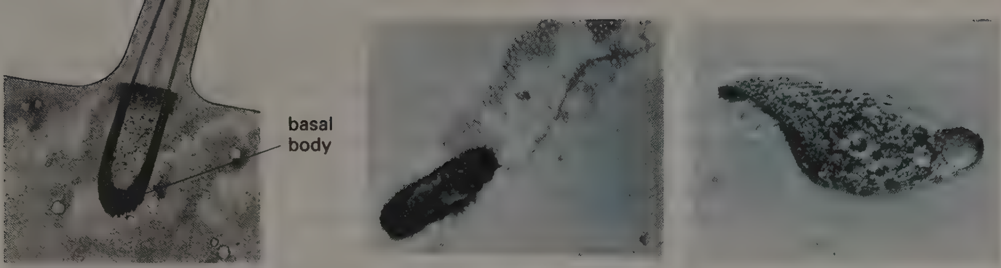
Centrioles* (SEN tree OHLZ) usually occur in pairs arranged at right angles to each other near the nucleus in many eucaryotic cells. Centrioles appear to function in cell division, which is discussed later.

A **flagellum*** (fluh JEL um) (pl., flagella) is a long, tubular extension of the plasma membrane surrounding a set of tiny tubes. Flagella are often longer than the cell and usually exist singly but sometimes occur in pairs or groups of 3, 4, or 5. **Cilia*** (sing., cilium) are similar to flagella but are usually shorter and frequently cover either the entire cell or a section of the cell.

At the base of each cilium or flagellum is the *basal body,* which resembles a centriole. The basal bodies or *kinetosomes** (kuh NET uh SOHMZ) help to control the action of the cilia or flagella. Cilia and flagella in eucaryotic cells beat in specific patterns. A flagellum acts somewhat like a

Answers–Review Questions 3A-3

1. The cytoplasmic matrix, the watery substance in which the granules are suspended, is a colloid made of proteins, fats, carbohydrates, ions, and small compounds in combinations that differ from cell type to cell type. It is very structured and goes from sol to gel and back again in order to stream within the cell.
2. They are found in the cytoplasm of both procaryotic and eucaryotic cells in association with rough ER. Some of them form the enzyme system necessary for protein synthesis.
3. ER consists of extensive folds of membranes running through the cytoplasmic matrix. In some cells it is the inward folding of the plasma membrane; in some, it is continuous with the membranes around the nucleus. Some ER (rough ER) is dotted with ribosomes. ER has membrane-bound enzymes that function in the synthesis of proteins, lipids, and carbohydrates into larger compounds. It also serves as channels for movement of substances within the cell.
4. (1) Leucoplasts are used as storehouses. (2) Chromoplasts contain pigments and are used in syntheses (especially chloroplasts).
5. A Golgi body is a system of flat, often curved saccules. It processes and packages complex polysaccharides, proteins, and lipids into membrane-bound sacs for excretion and assembles cellulose and polysaccharides found in cell walls and capsules.
6. They would digest the cell itself.
7. **(1)** A phagocytic vacuole engulfs food or foreign materials. **(2)** A pinocytic vesicle seals molecules too large to be absorbed in fluid-filled vesicles. **(3)** A food vacuole stores engulfed food material and is the site of digestion. **(4)** A



3A-13 *A basal body (left) and a flagellum (middle) and cilia (right) on microbes*

flagellum: (L. FLAGELLUM, little whip)

cilia: (L. CILIUM, eyelid)

kinetosome kineto- (to move) + -some (Gk. SOMA, body)

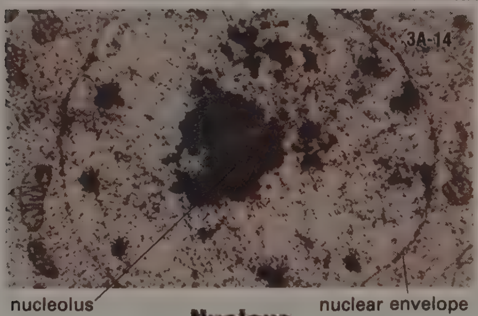
Page 71 shows a unicellular organism with a flagellum. Page 531 shows a group of ciliated cells seen from above. The cells in the top layer on page 75 are ciliated.

propeller, and cilia usually move in waves like a series of oars. The coordination of cilia or flagella is a function of the basal bodies.

Cilia and flagella do move unicellular organisms–the function they are most often associated with–but they are also quite common in multicellular organisms, where they often move the substances around the cell. The cells that line most of the human respiratory tract, for example, have cilia which move mucus and dust.

Review Questions 3A-3

1. Describe the cytoplasmic matrix.
2. Where are ribosomes found? Give the function(s) of ribosomes.
3. Describe and give the function(s) of the endoplasmic reticulum.
4. What are the two primary types of plastids? What are their functions?
5. Describe and give the function(s) of the Golgi body.
6. Why are the substances in a lysosome *not* released into the cytoplasmic matrix?
7. List several types of vacuoles and vesicles and give the functions of each.
8. What two structures contribute to the cytoskeleton?
9. Describe a microfilament and list several uses it has in cells.
10. Describe a microtubule and list several places it is found in cells. List several functions of microtubules.
11. What is the relationship between cilia (or flagella) and the basal body (kinetosome)?



Nucleus

The **nucleus** (pl., nuclei) is sometimes called the control center of the cell. Because it contains DNA, the nucleus has the coded information for protein manufacture. Proteins are used as building blocks and enzymes which enable cells to make and use all the other substances necessary for cell life. DNA indeed permits the activity of the cell. However, the DNA does not "decide" what a cell is to do or become. DNA cannot "decide."

The DNA that a cell has is a replicated copy of the DNA that was in the cell from which it came. Although a cell can make more DNA, this new DNA is only a copy of the cells original DNA. Since the cell has only a certain DNA with a certain structure, it is capable of making only certain proteins. When the need arises, a cell can stop making some proteins and start making others for which it has the DNA code. But it cannot make a protein for which it does not have the DNA code.

Carefully combat the idea that the nucleus controls something. That implies that the nucleus *decides,* which it cannot do. Nuclei were "programmed" by God at creation and have been functioning with the same basic instructions ever since (law of conservation). DNA responds to factors in its environment much like a computer responds to commands entered by the computer operator.

It appears that the protein does not always coat the DNA. In fact, it appears that the DNA is sometimes wrapped around the proteins.

waste vacuole contains indigestible materials and releases them through the plasma membrane in egestion. **(5)** A secretion vesicle is formed by the ER or a Golgi body, transfers synthesized materials to the plasma membrane, and releases them. **(6)** A central vacuole is filled with water. In most plant and algal cells, it causes turgor pressure. **(7)** A contractile vacuole collects water that enters the cell by osmosis (maintaining turgor) and secretes excess water to keep the cell from rupturing.

*8. Microfilaments or microtubules

*9. A microfilament is a flexible strand of protein molecules. Microfilaments form an internal boundary network of support in many cells. They direct cytoplasmic streaming in plant cells and are involved in the motion of human muscle cells. They are involved in the coordinated movement of cilia or flagella.

*10. A microtubule is an arrangement of protein molecules forming a tube. They are found in basal bodies, cilia, flagella, centrioles, and the aster. Microtubules are involved in the movement of cilia and flagella and in the movement of chromosomes in cell division.

11. At the base of the cilia or flagella in eucaryotic cells are found the basal bodies (kinetosomes). They have an arrangement of microtubules similar to that of cilia and flagella. Basal bodies appear to control the movement of the cilia or flagella.

*From a box.

chromatin: (color)

A cell's nucleus can be compared to the plant manager of a cloth mill. He may order the production of different kinds of fabric, depending upon various conditions and what fibers he can obtain. But he cannot have his plant produce cars. A cloth mill has the machinery to produce only cloth. If it made cars, it would not be a cloth mill.

Similarly, the nucleus of a cell directs the manufacture of proteins based on the DNA it has, but it cannot make protein for which it lacks DNA. Plant cells have the enzymes for manufacturing cellulose; animal cells do not. The DNA that the cell has, not a ''decision'' by the DNA or nucleus, makes the difference.

A cloth mill can make several kinds of cloth, depending on the fibers and the machinery. Likewise, a cell can adjust itself within the limits of its DNA. Not all the DNA in a cell is being used all the time. The ''turning on'' and the ''turning off'' of DNA in a cell account for the different cells which make up your body. All your cells have the same DNA, but not all of the DNA is functioning in each of your cells.

Structure of the nucleus

In eucaryotic cells the nucleus has a double membrane around it called the **nuclear envelope.** This envelope has large pores which permit the easy passage of material between the cytoplasm and the *nuclear sap,* the protein-rich fluid inside the nuclear envelope. In some cells this envelope is continuous with the endoplasmic reticulum.

Most cellular DNA is in the nucleus, where proteins appear to protect the long DNA molecule. The DNA and the proteins are the **chromatin***(KROH muh tin) **material.** If a growing cell is stained for nucleic acids, the chromatin material appears as a fuzzy mass in the nuclear sap.

In most cells stained to make the chromatin material visible, a darker area indicating high concentration of nucleic acids and associated proteins also appears. It is the **nucleolus** (noo KLEE uh lus), which contains relatively large amounts of RNA. Depending on the cell type, there may be no nucleolus, one nucleolus, or several nucleoli. The nucleolus appears to be involved with the transcription of the RNA found in ribosomes.

Biological Terms

cytology
protoplasm
The Cell Theory
cell theory
absorption
digestion
synthesis
respiration
movement
irritability
excretion
egestion
secretion
homeostasis
reproduction
unicellular
multicellular
colonial
tissue
organ
system
Structure of the Cell
eucaryotic
procaryotic
plasma membrane
cell wall
capsule (sheath)
cytoplasm
cytoplasmic matrix
cytoplasmic organelle
ribosome
endoplasmic reticulum
mitochondria
plastids
chloroplast
granum (pl., grana)
Golgi body
lysosome
vacuole
phagocytosis
cytoskeleton
microfilament
microtubule
pinocytosis
turgor pressure
centriole
flagellum (pl., flagella)
cilia (sing., cilium)
Nucleus
nucleus (pl., nuclei)
nuclear envelope
chromatin material
nucleolus

Review Questions 3A-4

1. It has been said that the nucleus of a cell is its control center. In what ways is this true, and in what ways is this not true?
2. List and describe the structures of a typical eucaryotic nucleus.

Thought Questions

1. In what sense would it be acceptable to call a unicellular or colonial organism a ''simple organism''? In what sense is it unacceptable to do so? Is it acceptable to call these organisms ''early organisms''? Why or why not?
2. In what ways are the plasma membrane, the cell wall, capsules, and sheaths really only the outer limits of a cell and not really the cell's boundaries?
3. Compare the human brain to the nucleus of a cell.

Answers–Review Questions 3A-4

1. The nucleus is the control center in the sense that DNA is primarily located there, and DNA determines the various enzyme systems a cell has by its protein synthesis. However, since DNA is not able to make decisions, it does not control the cell.
2. **(1)** Nuclear envelope–double membrane surrounding the nucleus; contains large pores; **(2)** nuclear sap–fluid in nucleus; **(3)** chromatin material–most cellular DNA; **(4)** nucleolus–contains RNA; location for transcription of RNA found in ribosomes

Answers–Thought Questions

1. It would be acceptable to call these organisms ''simple'' only if their microscopic size and lack of distinct tissues were considered. However, these organisms are very complex in the sense that each cell is capable of reproducing the entire organism. The term *early organisms* refers to their supposed evolutionary origin. This term is unacceptable, since the evolutionary theories are invalid.
2. These structures are parts of the living cell. They determine what enters and leaves the cytoplasm, and they protect the cell from severe environmental changes. They, therefore, form the outer limits of the cell itself for the benefit of the cell and are not simply structures which set its boundaries.
3. The human brain and nucleus of a cell are remotely similar because they are both vital to life. The brain, however, decides to do or not to do certain things. The nucleus is limited in what it can do to the program its DNA contains. A nucleus merely responds to its surroundings.

3B–The Living State of Cells

In Chapter 1 life was defined as a delicate balance of operations which faces death. We who live and are surrounded by living things often lose an appreciation for the narrow set of conditions in which every living thing must exist if it is to maintain the **homeostasis*** (HOH mee oh STAY sis) of life. *Homeostasis* means "steady state," but actually it is a *dynamic equilibrium,* meaning something that has to be worked at to remain the same.

When conditions are unfavorable, an organism must work harder to maintain the homeostasis of life. Consider a muscle cell in your arm that the body calls upon to contract and move your arm. If for some reason your body temperature has risen too high, the cell will not be able to function normally. Enzymes, for example, change as the temperature changes. Thus, as the temperature rises, some cellular processes will happen too fast, others too slowly. The muscle cell will be forced to slow down or stop certain of its normal processes. The change in temperature forces the muscle cell to alter its normal operations in order to restore its homeostasis. When it is called upon to contract, the cell may not be able to do so because of damage caused by the increased temperature. If the temperature gets too high or continues for too long, the cell will die.

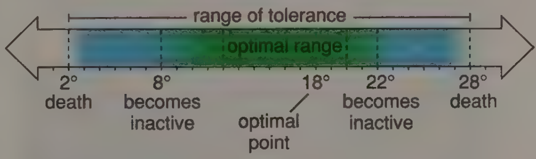
Optimal point and range of tolerance

Scientists call the point at which something functions best its *optimal* point* for a particular factor. The optimal point for temperature in your muscle cells is 37° C (98.6° F).

Most things have an *optimal range*. Within the limitations of the optimal range, an organism's or a cell's performance is about equal. Most human muscle cells, for example, will function equally well in temperatures within a degree or so from 37° C. The optimal range for a muscle cell is quite narrow when compared to the range of temperatures which are optimal for your body. You can function well and comfortably in rooms with temperatures from 16° C (60° F) to about 27° C (80° F), depending on the humidity, air currents, your clothing, and your activities. Despite this range of temperatures, your body maintains a constant temperature for its muscle cells.

If a muscle cell in your body is exposed to temperatures above or below its optimal range, your body tries to return it to its optimal range. Your body will shiver, perspire, channel your blood to different areas of your body, and use other means to keep your muscle cell at or very near 37° C. This is an example of an organism's working to maintain its homeostasis.

When the muscle cell gets warmer or cooler than its optimal range, it enters its *range of tolerance* for temperature. The range of tolerance is that range in which a cell or an organism will remain alive but not function properly. The farther from the optimal range the living thing is, the more poorly it functions. When at last it reaches its *limit of tolerance,* it dies.



3B-1 *Temperature (C) tolerance for a soil microbe*

The range of tolerance for heat and cold for a muscle cell is only a few degrees, quite narrow when compared to the range of tolerance for skin cells. Skin was designed to deal with the more extreme temperature fluctuations in the environment. Nerve cells, on the other hand, were not. They have a very narrow range of tolerance for temperatures; it is almost the same as their optimal range. Brain cells are extremely specialized nerve cells and must be kept within their optimal range for normal activity.

A cell, whether it is a unicellular organism or part of a multicellular organism, is able to tolerate certain fluctuations. All living things were designed with ranges of tolerance which cover the different conditions in their normal environments. This concept accounts for banana trees growing well in rainy tropics but growing poorly in deserts or on chilly mountaintops. It also explains why

homeostasis: homeo- (same) + -stasis (Gk. STASIS, a standstill)

optimal: (L. OPTIMUS, best)

A thermostat controlling a heater and an air conditioner can serve as a good example of homeostasis. The varying temperatures outside the home necessitate the thermostat if an equilibrium of temperature is to be maintained.

Consider using the following illustration to explain homeostasis before assigning the reading of this section:

A family can illustrate homeostasis. The family is largely dependent upon the electric company, the grocer, the water and sewer departments, and other agencies and suppliers for many of its needs. When all these needs are met, it is easy for the family to operate properly. This could be called the normal homeostasis of the family.

If the house is heated by natural gas, though, and suddenly the gas supply fails, the family will change its normal activities to attempt to maintain a livable temperature. Phone calls to the gas company would be a direct method of dealing with the problem. If phone calls produce no results, indirect methods must be used. If it were winter, family members would probably wear heavier clothing and put extra blankets on the beds. Perhaps the family would build a fire in the fireplace and seal off certain rooms of the house in order to ▶

3B–The Living State of Cells

Notes–Chapter 3B

This brief chapter contains several significant concepts that are recurring themes in this book. Be careful not to stress the examples so much that the students miss the major concepts.

Cells are walking a tightrope in order to maintain their living condition. They are designed to be in a specific environment. They have the mechanisms to deal with the normal fluctuations that happen in that environment. Going beyond what they are designed to deal with affects their ability to maintain life.

The solution around the cell is critical to its functioning. Permitting a substance to enter a cell, keeping a substance in (or out of) a cell, and working to get specific substances into a cell are also essential for the functioning of a cell.

Objectives–Chapter 3B

- ❑ Describe the relationship between a living thing and the various factors in its environment.
- ❑ Describe the effects of hypotonic and hypertonic solutions on cells. List and describe some ways cells that must live in these conditions are able to do so.
- ❑ List and describe two forms of passive transport of substances into cells.
- ❑ Describe active transport of substances into cells.

dormancy: (L. DORMIRE, to sleep)

isotonic: iso- (Gk. ISOS, equal) + -tonic (TONOS, tone or tension)

hypotonic: hypo- (Gk. HUPO, beneath or under) + -tonic (tension)

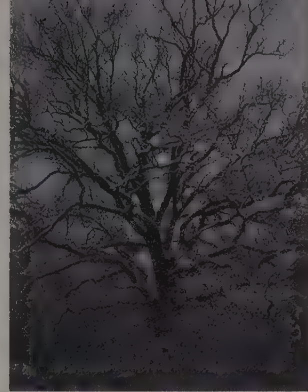
▶ conserve heat. If the lack of gas persisted, the family might be forced to start burning its furniture or even move out of the house.

The operations the family engaged in during the gas shortage were intended to maintain a comfortable living temperature–homeostasis. During the emergency, however, the family worked harder to remain alive. The steady state of homeostasis is harder to maintain under unfavorable conditions. Pages 471-72 and 478 deal with limiting factors in the ecosystem, which parallel the concepts of optimum range and range of tolerance.

All cells are in solution. The solution around the cell must be isotonic, hypotonic, or hypertonic. Various cells are designed to deal with a certain range of concentration gradients optimally. They also have a range of tolerance beyond which they die.

houseplants that do well in a kitchen window may not grow well in a window on the other side of the house.

There are organisms (and cells) that live in environments that change drastically in the course of a year. An organism whose environment normally fluctuates beyond its optimal range may enter a period of *dormancy** to survive unfavorable conditions. Adjustments made by some organisms (such as trees) in order to live through the winter are examples of dormancy. Winter-dormant organisms, however, will die if the temperature gets too cold and exceeds their limits of tolerance.



3B-2 *Freezing temperatures during a tree's growing period would kill the tree. During its dormancy freezing temperatures are within the tree's range of tolerance.*

Review Questions 3B-1

1. Why is homeostasis called an equilibrium? Why is homeostasis called dynamic?
2. Compare and contrast the optimal point, the optimal range, the range of tolerance, and the limit of tolerance.

The Solutions Around Cells

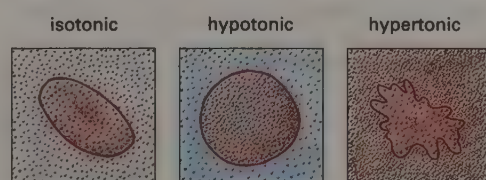
Whether a cell is in a multicellular organism or is a unicellular organism, it is in a solution. One of the most critical influences upon the existence of a cell is the concentration of materials in the solution around it. Of course, poisons or harmful substances in the solution affect the cell's homeostasis. Most cells cannot tolerate fat-soluble substances such as ether, alcohol, or chloroform because they dissolve the fats of the cellular membranes, enter the cell rapidly, and affect the normal functions of the cell's use of fats. Even weak concentrations of these substances take cells beyond their optimal range, and a slightly stronger concentration takes the cells beyond their range of tolerance and causes death. This is one reason that drinking alcohol is harmful.

Cells may have problems with normal and valuable substances like water, ions, and food dissolved in their environments. Too much of a good thing may harm cells as easily as too little.

Cells in solutions

The red blood cells in your bloodstream are good examples of cells in a completely controlled solution. The cytoplasm of the blood cells and the blood plasma (the fluid portion of the blood that surrounds the cells) have identical concentrations of solutes dissolved in them. The red blood cells of your body are in an **isotonic*** (EYE suh TAHN ik) **solution.** The solutes in the red blood cells are of a different nature than those in the plasma, but the ratio of solutes to water is the same inside and outside the cell membrane. Because there is no concentration gradient, there is transfer of molecules across the membrane, but there is no net osmosis.

If red blood cells are put in pure water, a concentration gradient is established. The outside of the cell has a higher concentration of water molecules and a lower concentration of solutes than



3B-3 *Blood cells in various solutions. In which is cytolysis about to take place? In which has plasmolysis taken place?*

Answers–Review Questions 3B-1

1. It is an equilibrium because it involves keeping a balance in body systems. It is dynamic because things must be changed in order to accomplish the equilibrium.
2. The optimal point is the point at which the cell or organism functions best. The optimal range is the limits within which it functions properly. The range of tolerance is the range within which the cell or organism will remain alive but not function properly. The limit of tolerance is the point at which the organism or cell can no longer function and dies as a result.

the inside. These red blood cells are in a **hypotonic*** (HYE poh TAHN ik) **solution.** The larger solutes, however, are unable to move out through the selectively permeable cell membrane. Water molecules, since they are very small and move freely through all cellular membranes, will rapidly diffuse into the red blood cells, causing them to expand and eventually burst. A cell's bursting from internal pressure is **cytolysis*** (sye TAHL ih sis).

If red blood cells are placed in a fluid with a concentration of solutes higher than that of the cells, the cells are in a **hypertonic*** (HYE pur TAHN ik) **solution.** In hypertonic solutions, water molecules will diffuse out of the cells. As the cell loses its water, it shrinks. Putting a cell in a hypertonic solution results in **plasmolysis*** (plaz MAHL ih sis)–a collapse of the cell's cytoplasm.

Red blood cells depend upon other parts of the body to keep the solutes in the blood plasma at exactly the right concentration. They therefore do not have mechanisms within them to adjust to different plasma-solute concentrations. Since these cells lack these mechanisms, an intravenous feeding solution or an injection must have the same solute concentration that the blood plasma does. If it does not, plasmolysis or cytolysis of the blood cells may occur, resulting in death.

If a physician wants to administer a large quantity of some medicine, he cannot give an extremely concentrated injection. He must instead give the medicine in a special amount of a solution which matches the concentration of the blood plasma.

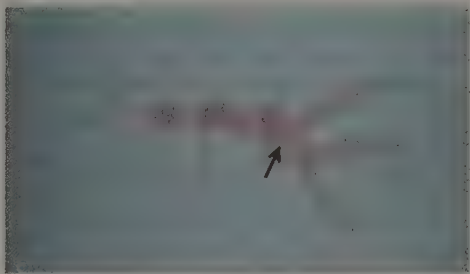
Because most cells in multicellular organisms are in nearly constant isotonic solutions, they have few, if any, mechanisms to deal with hypotonic and hypertonic solutions. For many colonial or unicellular organisms, however, hypotonic or hypertonic solutions are a constant environment.

Cells in hypotonic solutions

Since fresh water has fewer dissolved substances than the cytoplasm of a cell does, a unicellular organism that lives in fresh water exists in a hypotonic solution. The unicellular and colonial organisms found in such aquatic environments must therefore either deal with the concentration gradient that is around them or die.

Many cells that live in aquatic environments have rigid cell walls which prevent cytolysis. The physical strength of the cell wall serves as a pressure against the concentration gradient. Once a certain amount of water has diffused into the cell and into the central vacuole, the cell becomes *turgid* (TUR jid). When the cytoplasm is pushing against the rigid cell wall, there is a physical pressure set up. Although the concentration gradient may favor water molecules moving into the cell, the pressure caused by the presence of the cell wall opposes them. This pressure against water entering the cell stops osmosis and prevents cytolysis.

Many cells in hypotonic solutions, though, must have a flexible membrane. A cell wall would restrict the movement and food-getting processes of many protozoans. Since many protozoans do not have cell walls, they must have other methods



3B-4 *The clear area near the dark nucleus is a contractile vacuole.*

not have cell walls, they must have other methods to survive their hypotonic environment. To do so, many of them have **contractile vacuoles.** As water molecules diffuse into the cell, they are collected in little vesicles or in arms of the contractile vacuole. The vesicles or arms then pass the water to the contractile vacuole. Once the contractile vacuole has collected enough water and reached a certain size, it fuses with the plasma membrane and forces the water outside the cell. This process requires the cell to expend energy.

cytolysis: cyto- (cell) + -lysis (a loosening)

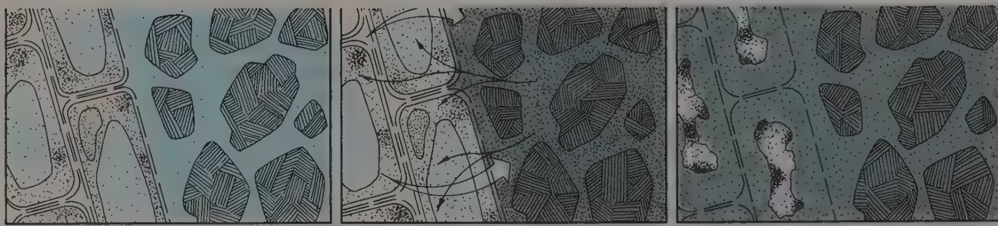
hypertonic: hyper- (Gk. HUPER, over or beyond) + -tonic (tension)

plasmolysis: plasmo- (to mold) + -lysis (a loosening)

Different cells have different ranges of tolerance for water and solute concentrations. Blood cells have a narrow range of tolerance. Amebas, like the one pictured in 3B-4, have a wider range. Amebas can tolerate certain hypotonic solutions, while hypertonic solutions quickly kill them.

Visual 3B-1 can be used to teach the terms *isotonic, hypotonic,* and *hypertonic.* Use colored pens to show how the various substances (small dots for water, larger dots for dissolved materials) would travel into or out of the illustrated blood cell. Use black to show how the cell membrane will react (swelling or collapsing).

Some early microscopists thought contractile vacuoles were hearts because they appeared to be pumping. One of the ways to tell if a protozoan is living is to look for the operation of its contractile vacuoles. Contractile vacuoles are also discussed on pages 261, 263, and 265.



3B-5 Fertilizer burn. (left) *Normal conditions;* (middle) *The addition of fertilizer increases the solute concentration outside the cell, resulting in the movement of both water and solutes;* (right) *Solutes entering and water leaving the cell result in plasmolysis and possibly death of the plant.*

Salmon hatch in freshwater streams, swim into the ocean, and later return to the streams to breed and die. Most fish, if forced from freshwater into salt water or from salt water into freshwater, die as the cells in their gills experience plasmolysis or cytolysis. Salmon have the body mechanisms necessary to deal with the extra salt entering their bodies from the hypertonic sea water. These mechanisms involve changes in the membranes of gill cells, excretion by the kidney, and absorption of salt into the gut lining. Salmon are able to adjust to these changes; many other fish are not (also see p. 402).

Page 53 gives the example of human consumption of sea water. This example can be used effectively to illustrate solute concentrations around cells.

Cells that are normally in highly concentrated salt solutions (like the gill cells of salt-water fish) have mechanisms that prevent the salt concentration of the cytoplasm from going too high. In these fish the salt is collected in the blood and secreted from the body by processes that most freshwater fish lack.

If a cell with a contractile vacuole is placed in water that has a lower concentration of solutes than the water it is accustomed to, the contractile vacuole begins to work faster. If a cell with a contractile vacuole is placed in nearly pure water, the diffusion of water molecules into the cell is so rapid that, despite the rapid working of the contractile vacuole, cytolysis will soon occur.

Cells in hypertonic solutions

Most cells are not equipped to deal with hypertonic solutions as well as they deal with hypotonic solutions. With the exception of those cells directly exposed to seawater, most cells do not find themselves naturally in situations with hypertonic solutions. Man, however, occasionally puts cells in hypertonic solutions and then wonders why they do not thrive.

For example, some homeowners, thinking that "if a little is good, a great deal must be better," put more fertilizer on the soil around their plants than the directions on the package suggest. The fertilizer dissolves into the soil. If too much has been applied, the root cells may be in a hypertonic solution. As the ions of the fertilizer enter the cell and the water leaves the cell to equalize the concentration gradient, the cell first loses its turgidity and then experiences plasmolysis, which results in cellular death. If this occurs to enough root cells, the plant may die and turn brown. The plant requires the ions found in fertilizers, but it cannot use too much.

Plant cells are sometimes temporarily short of water. Hot days can cause water to evaporate from leaves more rapidly than it is replaced from the roots. The results are the same as if a hypertonic solution surrounded the cells. Water molecules leave the cells and enter the atmosphere. This causes the cells to lose their turgidity, and the plant wilts. Under normal situations a cooler evening and night will permit the plant to restore turgidity by obtaining water from the soil without losing it by evaporation. If the wilting continues because of a lack of water in the soil or because of damage to the plant, the cells will experience plasmolysis and die.

The drooping of cut flowers and the limpness of lettuce is caused by the loss of turgor due to the situations similar to hypertonic conditions. Abundant, cool, fresh water will restore turgor to a salad or bouquet–unless plasmolysis has already occurred.

Review Questions 3B-2

1. Compare and contrast isotonic, hypotonic, and hypertonic solutions.
2. List two methods some cells have for withstanding hypotonic solutions and explain how they operate.

How Substances Enter Cells

Most of what we have discussed thus far about materials entering cells can be explained as diffusion through the semipermeable plasma membrane. In their fight for homeostasis, however, cells must often move substances against the concentration gradient. Some substances are not permitted into and others not permitted out of the

Answers–Review Questions 3B-2

1. An isotonic solution has exactly the same concentration of solutes as the cytoplasm of the cell; no diffusion or osmosis occurs. A hypotonic solution has a lower concentration of solutes and, therefore, a greater concentration of water than the cell cytoplasm (or another solution). Cytolysis may result in cells placed in such a solution. A hypertonic solution contains a greater concentration of solutes than do living cells. Putting cells into such a solution may cause plasmolysis.
2. (1) Cell wall rigidity occurs when turgor pressure opposes osmosis of water into the cell. (2) Contractile vacuoles collect diffused water, fuse with the plasma membrane, and force water out of the cell.

cytoplasm, even though those substances should, it seems, diffuse through the membrane easily.

Some substances enter cells rapidly, others slowly. The ability of a substance to enter the membrane of various cells may be vastly different. Cells unable to ingest certain nutrients surrounding them will starve. Yet other cells in the same solution may grow rapidly because they are able to utilize the nutrients.

Cells are designed for specific environments. Some cells may not be able to adjust to a situation foreign to them even though these same conditions might be ideal for other cells.

Passive transport across membranes

Molecules often pass through a plasma membrane without expending cellular energy. **Passive transport** is the movement of molecules through a membrane *with* the concentration gradient. Kinetic energy of the molecule, not the cell, supplies the force behind passive transport.

3B-6 Factors Which Determine Whether a Molecule Will Pass Through a Cellular Membrane

- concentration of the molecule (diffusion pressure)
- size and weight of the molecule
- shape of the molecule
- charge of the molecule
- fat-solubility of the molecule
- permeability of the membrane

One factor is the concentration of the molecule on both sides of the membrane. If the diffusion pressure is high, the molecule travels more rapidly across the membrane. Size is another factor. Very small molecules such as water and gases (oxygen, carbon dioxide, and nitrogen) seem to pass easily through almost all cellular membranes. Some other very small molecules and ions, however, pass through membranes slowly.

The properties of a substance and the permeability of the membrane to that substance determine which molecules will pass through and how rapidly. The shape of the molecule affects its permeability. Some long thin molecules pass slowly through membranes while round molecules of the same size and mass do not pass. Fat-soluble molecules appear to dissolve the phospholipids of a membrane and penetrate more quickly than molecules that are not fat-soluble.

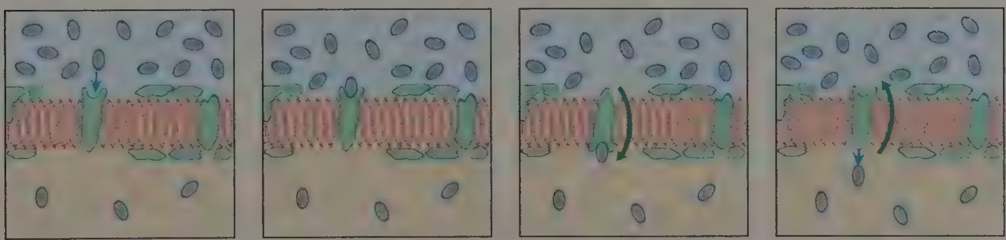
Small molecules like monosaccharides, amino acids, fatty acids, and glycerols penetrate slowly through plasma membranes. Disaccharides and molecules that are physically larger (such as polysaccharides and proteins) penetrate even more slowly. Lipids barely penetrate membranes at all.

Passive mediated transport across membranes

For years scientists were baffled that some cells permit the penetration of certain large molecules (usually specific carbohydrates or proteins) but exclude the passage of other molecules of similar size and properties. The large molecules that penetrated were varied in different cells.

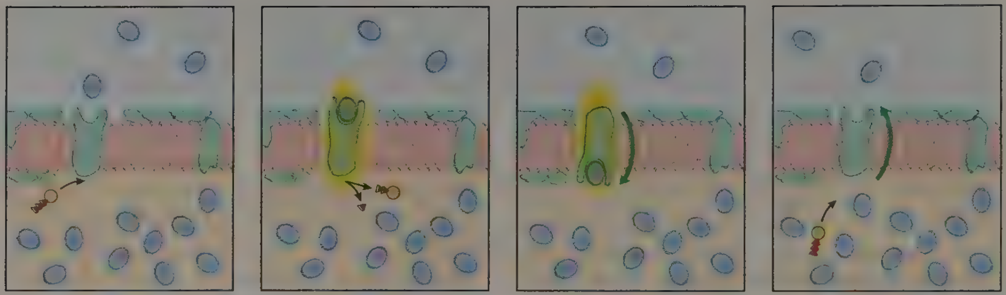
This is a passive transport since it requires no cellular energy and goes either into or out of the

3B-7 *In passive mediated transport, molecules are being moved across the membrane by a membrane factor. Passive mediated transport goes with the concentration gradient.*



Visual 3B-2 can be used to present the factors that determine if a molecule will pass through a cellular membrane.

Visual 3B-3 outlines how substances enter cells. It can be used to help teach this material.



3B-8 *Active transport requires cellular energy and moves molecules across a membrane against the concentration gradient.*

cell, depending on the concentration gradient. But this transport does require the presence of a factor in the membrane; therefore, it is called **passive mediated transport.**

In passive mediated transport the combination of the molecule with the membrane factor permits the molecule to move across the membrane. Although most of these membrane factors are proteins, other molecules may be used as well. Scientists believe that some antibiotics work this way; that is, they change membrane permeability by supplying or affecting factors for passive mediated transport.

Active transport across membranes

Enzymes in the plasma membrane carry on **active transport,** the movement of molecules across membranes *against* the concentration gradient. Since these enzymes require energy to function, active transport involves the expenditure of cellular energy. The entry of nutritive substances or the elimination of molecules in the cell's environment is often done by active transport.

For example, active transport occurs when mineral ions are absorbed by root cells of plants. These ions exist in lower concentrations in the water outside the root than inside the root cells. However, live cells must expend energy by the active transport of ions into the cell. If oxygen, which is necessary for most cells to expend their stored energy, is absent, active transport stops. Because the ions can no longer be absorbed, the cell dies.

Biological Terms

homeostasis
The Solutions Around Cells
isotonic solution
hypotonic solution
cytolysis
hypertonic solution
plasmolysis
contractile vacuole
How Substances Enter Cells
passive transport
passive mediated transport
active transport

Review Questions 3B-3

1. Name the two primary methods by which molecules enter cells through membranes.
2. List several factors affecting passive transport of molecules through plasma membranes.
3. List two conditions necessary for passive mediated transport across a membrane.
4. List the conditions necessary for active transport across a membrane.

Thought Questions

1. Give three examples of how your body adjusts to maintain your homeostasis when your environment changes.
2. If a person were to drink salt water, what type of solution would the cells of the digestive system be in? Would this result in cytolysis or plasmolysis? Explain.

Answers–Review Questions 3B-3

1. (1) Passive transport (not requiring energy); (2) active transport (requiring energy)
2. (1) Concentration of molecules inside and outside membrane; (2) size and weight of molecule; (3) shape of molecule; (4) charge of molecule; (5) fat solubility of molecule; (6) permeability of membrane
3. (1) Presence of a membrane factor; (2) concentration gradient
4. (1) Presence of oxygen for energy expenditure (most cells require oxygen); (2) membrane enzymes

Answers–Thought Questions

1. (1) Perspiration; (2) change in heart rate and respiration rate; (3) elimination of wastes
2. The cells would be in a hypertonic solution. It would cause plasmolysis because the cytoplasm of the cells would lose water into the salt solution.

CELLULAR PROCESSES
CYTOLOGY PART II

FOUR

Time Frame
4A: 1-2 periods without *A Closer Look at Photosynthesis* (pp. 94-95) and *A Closer Look at Cellular Respiration* (pp. 98-99). Adding these pages could add 1-2 periods.

4B: 1-2 periods without the Facet and the *Metabolism and Homeostasis* section (pp. 109-10).

Facet *(Interrelated Metabolisms)* and the *Metabolism and Homeostasis* section: 1 period.

Laboratory Activity
4–*Photosynthesis* is designed as a demonstration of factors affecting this process.

4A–Cellular Energy

Although cells also depend upon many other conditions in the environment, a constant supply of energy is necessary for cells to carry on all their cellular processes. Cells constantly use energy to maintain their homeostasis, even when they are in the most favorable environments. Energy is used to manufacture needed substances and to tear down others. Expenditure of energy is a primary attribute of life. When cells stop using energy, they are dead.

Cells use amino acids and other substances over and over again in making large different molecules. Energy, however, is a one-time commodity; every time it is used, some escapes and becomes useless. Cells must use energy to make energy-storing molecules. Since some energy escapes with every energy transaction, more energy is needed to *build* an energy-storing molecule than is *stored* in the molecule. To make any large molecule, cells need large quantities of energy.

4–Cytology Part II: Cellular Processes

By this stage of schooling, students should know the names and functions of a number of cellular structures. In high school a basic understanding of how those functions are accomplished and how they are interrelated should be added in order to give a solid foundation to the rest of the study of biological processes.

In Chapter 3 students were exposed to far more extensive lists and physical descriptions of cellular parts than they had experienced in previous classes. But a list and description of parts, no matter how extensive, does not give a good picture of how something works. Knowing the physical characteristics of a muscle is of little help in knowing what to do when it hurts. That knowledge comes only with knowing *how* a muscle works.

It is far more difficult to understand and, therefore, to teach how a muscle works than it is to understand and teach that there is a muscle and that it works. The same holds true of teaching cellular physiology compared to teaching cellular anatomy. Because something is difficult, however, does not mean it should be omitted. Decisions to omit or skim material should be based on immediate and long-term values as well as its importance to the learner's future spiritual decisions.

There can be immediate values to a student's understanding cellular processes (e.g., healthful changes in diet and exercise, ability to judge the claims of food and drug manufacturers). There are spiritual decisions that students will need to make that a knowledge of cellular processes can influence. But these generally seem distant and somewhat insignificant to most students and some teachers.

The following can be used to justify the teaching of this difficult material (and therefore to motivate the teacher and the

autotroph: auto- (self) + -troph (Gk. TROPHE, nourishment)

heterotroph hetero- (Gk. HETEROS, other) + -troph (nourishment)

photosynthesis: photo- (Gk. PHOS, light) + -syn- (together) + -thesis (to place)

Emphasize that the primary need of all cells is energy. It is the only cellular need which is not recyclable in the environment. There must be a constant supply. Pages 462-65, 469, and 471 speak of energy in the ecosystem, which directly parallels energy in cells.

Ecological terms that mean virtually the same thing are producers (autotrophs) and consumers (heterotrophs), spoken of on page 462. Chemosynthetic bacteria were once believed to be insignificant. Scientists are finding that these bacteria are vitally important in certain ecosystems.

Point out that there are two kinds of autotrophic organisms: photosynthetic and chemosynthetic (see p. 96).

Students should not memorize this equation. It is incomplete (unbalanced).

Stored energy in large molecules is of value to the cell primarily when it is being used. Every time a large molecule is broken apart by the cell to get this stored energy, some of the energy escapes. As a result, the amount of *usable* energy in an energy storage molecule is considerably less than the total amount of energy in the molecule.

Cells constantly battle to maintain a supply of energy. Energy–crucial for all life–is the one commodity that is stored (but not without considerable loss), is used (but never reused), and escapes constantly. Yet *all* living cells need energy at *all* times.

Autotrophs and heterotrophs

Organisms can be classified into two groups, depending on how they obtain their energy. Organisms that make their own food are called **autotrophs.*** Plants, algae, and other organisms are able to capture light energy and make their own food. These are the primary autotrophs. Organisms that depend on other organisms for their energy are called **heterotrophs.*** These include animals, fungi, and most bacteria.

Photosynthesis, the process used by most autotrophs in storing energy (making their food), will be discussed in the next paragraphs. Cellular respirations, the processes all organisms (including autotrophs) use to release energy from storage, will be discussed in the next section.

Photosynthesis

On our planet the sun is the ultimate source of energy used by living things. The sun heats our planet. But warmth, though essential, is not the energy needed to keep living things alive. Chemical energy is necessary for the reactions that maintain the life.

But the sun's energy does not come as chemical energy. Instead, certain organisms are capable of absorbing light energy and converting it into stored chemical energy. This process is called **photosynthesis.*** Green plants and algae, the primary photosynthetic organisms, perform this essential energy transformation not only for themselves but also in large enough quantities to supply stored chemical energy for almost every living thing. Because it is the essential step between solar energy and life, photosynthesis is one of the most important biological processes.

History of man's knowledge of photosynthesis

Man has long recognized his dependence upon plants for his food. Even the meat you eat comes from animals that ate plants. Before the seventeenth century people believed that plants obtained their substance from the soil. Van Helmont's famous tree experiment (see page 8) demonstrated that most of a plant's substance does not come from the soil. Van Helmont drew the conclusion that virtually all the substance of a plant is water. He was only partly right.

In 1772 Joseph Priestly conducted experiments with air. He discovered that if he burned a candle in a closed jar, the resulting ''impure air'' would kill a mouse put into the jar. He also noted that if a sprig of mint was placed in the jar, the air apparently changed so that the mouse would not die. About seven years later it was discovered that the plant in the jar must be exposed to light in order for this change in the air to take place.

4A-1 *Priestly's experiments with air*

The basic information was clear: green plants use water, affect the air, require light, and make organic matter. In the next hundred years scientists used refined techniques to uncover other facts about the process and formulate the basic concept of photosynthesis.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \text{light energy} \longrightarrow \underset{\text{sugar (glucose)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{O_2\uparrow}$$

students): first, these processes are significant biological processes that are used by all living things and are fundamental to their operation. Humans may not carry on photosynthesis, but without it, physical existence would not be possible. If life depends on something, it is important to have at least a passing knowledge of it. Stress the universality of these processes and how they relate to humans. Use it to motivate the students and to broaden their understanding.

Second, a knowledge of these processes is necessary to understand other biological facts and concepts. As the students would put it, ''To get the stuff in the next chapters, you gotta get this stuff first.'' One cannot understand the significance of mitosis and meiosis without first understanding the significance of DNA and protein synthesis. Understanding mitosis and meiosis helps one understand genetics, which enables one to understand arguments against evolution and for creation and understand what is a good position on genetic engineering and human eugenics. Christians often have difficulty making decisions and taking positions on such things because they have only a superficial understanding of the topic. Chapter 4 contains much of the needed foundational material. Teach with this in mind.

4A–Cellular Energy

Notes–Chapter 4A

Energy is the most critical need of cells. How cells obtain and process energy is essential to an understanding of how cells operate.

Although this material may seem complicated on the surface, the presentation given here is straightforward and not complex. Unfamiliarity and the ''smallness'' of what is being dealt with are more of a problem than any inherent, confusing complexity. The teacher's approach and attitude often has more to do with the students' ability to understand this material than the diffi-

ATP—The Energy Currency in Cells

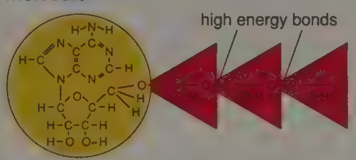
Imagine going to a vending machine, reaching into your pocket for a quarter, but finding that all the money you have is a $10 bill. You have enough money for the item that you want, but you cannot get it because you do not have the amount in a usable form.

Similarly, a cell may have many molecules of starch or lipids, but there is *too much* energy in these molecules to be used all at once. If all the energy in a molecule of starch or lipid were released in a cell at one time, that area of the cell would be destroyed. The energy from these molecules must be converted to smaller, usable units. In living organisms, that smaller unit is the energy that is stored in a molecule of **ATP-adenosine triphosphate** (uh DEN uh SEEN ◊ try FAHS FAYT). ATP, you could say, is the penny of cellular energy currency.

ATP is a molecule composed of adenosine (made of a simple sugar and adenine) and three phosphates. Between the phosphates are *high energy bonds*. Although these bonds are unstable, they contain a usable quantity of chemical bond energy. When one phosphate breaks off an ATP molecule, the reaction produces **ADP-adenosine diphosphate** (uh DEN uh SEEN ◊ dye FAHS FAYT), a phosphate, and energy from the bond. The reaction can be written as follows:

$$ATP \rightarrow ADP + P + energy$$

ATP molecule:



adenosine + phosphate + phosphate + phosphate

The amount of energy transferred in this reaction is adequate to accomplish many cellular functions requiring energy. Occasionally two or more ATPs supply the energy for a single reaction. Active transport, biosynthesis of molecules, cellular movement, and locomotion are all possible because of energy released from ATP molecules.

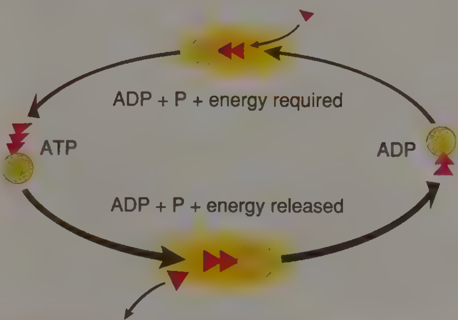
Your muscles use ATP energy to contract. But ATP cannot be brought to muscles through the

blood. ATP is very unstable. The flow of blood would break ATP down to ADP plus a phosphate long before it reached your muscles. ATP is a temporary, unstable energy-storage molecule and must constantly be manufactured by every cell as long as it is alive.

An ATP molecule that has given off its energy and has become an ADP plus a phosphate can be reused. With the proper enzymes and an adequate supply of energy, the ADP and a phosphate can recombine to form ATP. The reaction can be summarized as follows:

$$ADP + P + energy \rightarrow ATP$$

A normal adult male uses about 2,800 kilocalories (or 2,800 cal.) of energy a day. That converts to about 5,250 oz. (150 kg) of ATP a day. In a person's body at any given time there is only about 0.175 oz. (0.005 kg) of ATP. Your body must constantly make ATP from ADP and energy if you are to stay alive.



This box presents a description of the energy-storage molecule ATP. This material is crucial to understanding many cellular functions in the next two chapters and in the human physiology section. It should be covered thoroughly.

The terms **ATP (adenosine triphosphate)** and **ADP (adenosine diphosphate)** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Note the color and shape of the ATP/ADP molecule. It will be used repeatedly in later pages. Students should not be expected to memorize the structural formula, but stress that high-energy bonds (represented by ~) exist between the phosphates.

Often the phosphate is transferred temporarily to the molecule that is receiving the energy.

Visual 4A-1 can be used to present the material regarding ATP and ADP.

culty of the material. Do not tell them it is easy, but tell them it is logical, straightforward, and understandable. Then be sure your presentation is the same.

Objectives–Chapter 4A

- ❑ Understand the significance of ATP and ADP in cellular energy systems.
- ❑ Understand the significance of photosynthesis to the processes of life.
- ❑ Write a simple chemical equation for photosynthesis.
- ❑ Describe the light and dark reactions of photosynthesis.
- ❑ Understand the significance of cellular respiration to the processes of life.
- ❑ Write a simple chemical equation for aerobic cellular respiration.
- ❑ Note the efficiency of cellular respiration compared with lactic acid fermentation and alcoholic fermentation.

The box dealing with ATP (above) is as essential to understanding cellular energy as ATP is to cells. Do not omit it. The boxes *A Closer Look at Photosynthesis* and *A Closer Look at Cellular Respiration* (pp. 94-95, 98-99) are actually summaries of current models of these processes. Much more is known of these processes than is presented in these boxes. Students should be exposed to this material if possible. It is good for them occasionally to stretch to understand something significant that they will find useful in studying later chapters. Students with good foundational training in science should be able to deal with these processes on this level. If, however, stu-

chlorophyll: chloro- (greenish yellow) + -phyll (Gk. PHULLON, leaf)

Follow the natural progression of photosynthesis used in the text. To jump into the details of pages 94-95 would be confusing. Start with a historical look and build a simple formula; discuss the need of a catalyst (light, CO_2, and H_2O do not spontaneously become sugar); describe chlorophyll; discuss Calvin's contributions and build a better formula; discuss the details of photosynthesis as scientists view it today (pp. 94-95, optional), and list the conditions for photosynthesis as a review of the process.

Students should know Dr. Calvin's work because of the significance of his accomplishments.

Note the color and shape of the chlorophyll molecule. This symbol will be used on later pages. Note also the Mg and N atoms in the center of the molecule and that all the other atoms are C, H, or O. Students should not be expected to memorize this molecular structure.

This box presents that there are other light-absorbing pigments in cells. The material presented in this box is supplemental but can easily be covered quickly in most classes. There are no terms from this box in the Biological Terms section at the end of the chapter.

Until the 1900s it was believed that the process of photosynthesis happened all at once as the equation indicates. Work by Dr. Melvin Calvin in the middle of this century, however, indicated that photosynthesis is actually a series of steps. Calvin exposed a unicellular algae to radioactive isotopes of carbon and oxygen in the form of carbon dioxide or water. He exposed the algae to varying periods of light and then killed the algae. The radioactive water and carbon dioxide were traced into the various products formed during photosynthesis. Much of our present knowledge of the process of photosynthesis is the result of Calvin's work, which earned him a Nobel Prize in 1961.

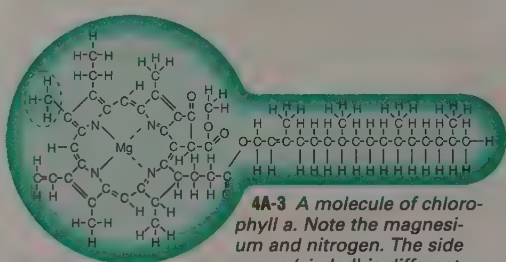
4A-2 *Dr. Melvin Calvin and the "lollypop" that he used to discover information about photosynthesis*

Review Questions 4A-1

1. What is the primary need of all cells?
2. What are the two major groups of organisms, based on how they obtain their energy?
3. Describe an ATP molecule. What is its function?
4. What is the difference between ADP and ATP? Which holds more energy?
5. What is the primary reason for photosynthesis?
6. List (a) the materials necessary for and (b) the materials produced by photosynthesis.

Chlorophyll and light

Chlorophyll* (KLOHR uh fil), a green-colored pigment, is the primary catalyst of photosynthesis. It has a head portion containing a single magnesium atom and a tail containing a carbon chain. A chlorophyll molecule does not contain iron, but iron appears to be necessary for its formation. In fact, chlorophyll is made only when the cell has a supply of iron and is exposed to light. Plants grown in reduced light or in iron-poor soils lack chlorophyll and appear pale yellowish or whitish.



4A-3 *A molecule of chlorophyll a. Note the magnesium and nitrogen. The side group (circled) is different in different types of chlorophyll.*

Other Plant Pigments and Photosynthesis

There are at least four different types of chlorophyll, designated chlorophylls *a, b, c,* and *d.* Chlorophyll *a* is a bright blue green and has the formula $C_{55}H_{72}O_5N_4Mg$. Chlorophyll *b,* which often accompanies chlorophyll *a* in seed plants, differs only slightly in the amount of hydrogen and oxygen: $C_{55}H_{70}O_6N_4Mg$. Chlorophyll *b* appears a yellow green.

Other pigments often coexist with chlorophylls in many photosynthetic cells. Although these other pigments are usually in considerably lower quantities than the chlorophylls, they often are abundant enough to alter the color we see. Neither these pigments nor chlorophylls *b, c,* and *d* carry on photosynthesis. Rather, they absorb wavelengths of light energy that are not absorbed by chlorophyll *a* and pass that energy to chlorophyll *a* to be used in photosynthesis. In this way plants in dim light can use more wavelengths of the available light.

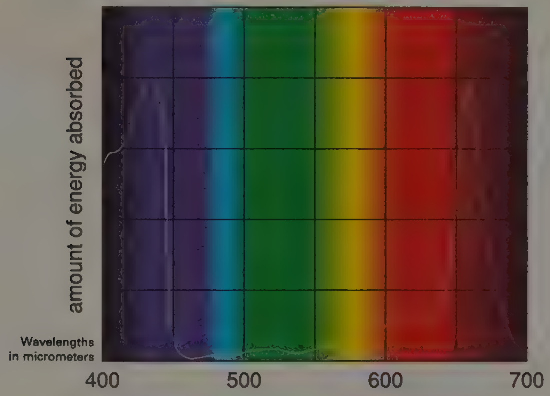
dents are having difficulty, this may be an ideal area to skim or skip.

Answers–Review Questions 4A-1

1. Energy
2. Autotrophs and heterotrophs
3. ATP is composed of adenosine (simple sugar and adenine) and three phosphates. High-energy bonds between the phosphate groups allow energy storage in the molecule. When one phosphate breaks off, energy is released, producing ADP + energy + phosphate.
4. ATP has three phosphates; ADP has two phosphates. ATP has more energy than ADP does.
5. To convert light energy to chemical energy, a storable form
6. **(a)** CO_2, H_2O, light energy; **(b)** sugars, O_2

Chlorophyll and other light-capturing pigments are found in the grana of the chloroplasts in photosynthetic eucaryotic cells. The chlorophyll appears to replace a number of the lipids in the membranes of the grana.

White light has wavelengths of all the colors of light. A prism can separate the wavelengths into a spectrum of color. Actually, when something appears red, it is reflecting red light waves and absorbing all the others. This should tell you what wavelengths, or colors, of light are necessary for photosynthesis.



4A-4 *Colors of light absorbed by chlorophyll a*

Since chlorophyll *a* is a blue green pigment, it is safe to assume that it reflects the blues and the greens, and absorbs the violets and the reds. Chlorophyll *b* is yellow green and therefore absorbs some of the same colors as chlorophyll *a*, but it also absorbs some of the blues not absorbed by chlorophyll *a* and rejects a few of the yellow-greens that chlorophyll *a* absorbs.

The process of photosynthesis

In some of Calvin's photosynthesis experiments with algae, he used water and carbon dioxide molecules that contained the radioactive isotope oxygen-18. This radioactive isotope degenerates, releasing radiation which can affect photographic paper. By taking "pictures" of the algae that had been exposed to radioactive water or carbon dioxide, Calvin learned what happened to these two different molecules during photosynthesis.

In one set of experiments Calvin exposed the algae to normal carbon dioxide and radioactive water. He found that the oxygen which was given off by the process of photosynthesis was all oxygen-18. None of the sugar produced had any oxygen-18 in it. Note the following equation for photosynthesis:

$$12H_2O^* + 6CO_2 + \underset{\text{energy}}{\text{light}} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2^* \uparrow$$

Students should memorize this formula for photosynthesis.

The oxygen-18 which Calvin used is indicated by an asterisk (*). The 12 molecules of water on the left supply the 12 atoms of oxygen (6 oxygen molecules, O_2) given off. The water on the right side of the equation is new water. You cannot reduce the formula by canceling 6 water molecules from each side since the water molecules on one side are not the same water molecules on the other side. Later studies demonstrated that the oxygen in the glucose molecule came from the carbon dioxide. This, then, indicates that water is a by-product of photosynthesis.

Note which colors are absorbed and which colors are reflected by chlorophyll *a*. Ask students why plants appear green.

$$12H_2O + 6CO_2 + \underset{\text{energy}}{\text{light}} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2 \uparrow$$

Visual 4A-3 can be used to review the conditions for photosynthesis.

Further experiments with carbon-14 helped to establish the accuracy of this simplified equation. The equation of photosynthesis given above is balanced, as the arrows beneath the substances indicate.

What has happened to the light energy put in on the left side? No energy is expressed on the right side. Some energy, of course, has been lost. Energy was used to make the new water and to put together the glucose molecule. In other words, the energy that did not escape is now in the molecules which have been made by the process. The energy in the product's water and oxygen is of little use to the organism, but the energy stored in the glucose molecule will be used to carry on cellular processes.

Ask the students for the conditions necessary for photosynthesis and list them on the board. The list should be considerably longer than the one in these paragraphs. Have them explain why these conditions are necessary. If the material on pages 94-95 has been covered, the students should have more specifics (such as supply of hydrogen and electron acceptors) than are outlined here.

Conditions for photosynthesis

Adequate supplies of the right wavelengths of light are necessary for photosynthesis. If they do

photolysis: photo- (light) + -lysis (a loosening)

This box should be covered by advanced classes or advanced students. An average class can grasp the material, but it may require class time better spent on other topics. This material is common in standard high school biology texts and is frequently found on standardized tests.

The terms **photo phase, dark phase, photolysis, PGA, PGAL,** and **RuDP** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Today much is made of cyclic photophosphorylation, noncyclic photophosphorylation, photosystem I, and photosystem II. These processes have been greatly summarized in this text. Students who continue with their biological studies may find a study of these advanced topics helpful. It would replace (covering in more detail) the material presented as the photophase. For most students such depth is unnecessary. Information about these processes can be found in many college level texts.

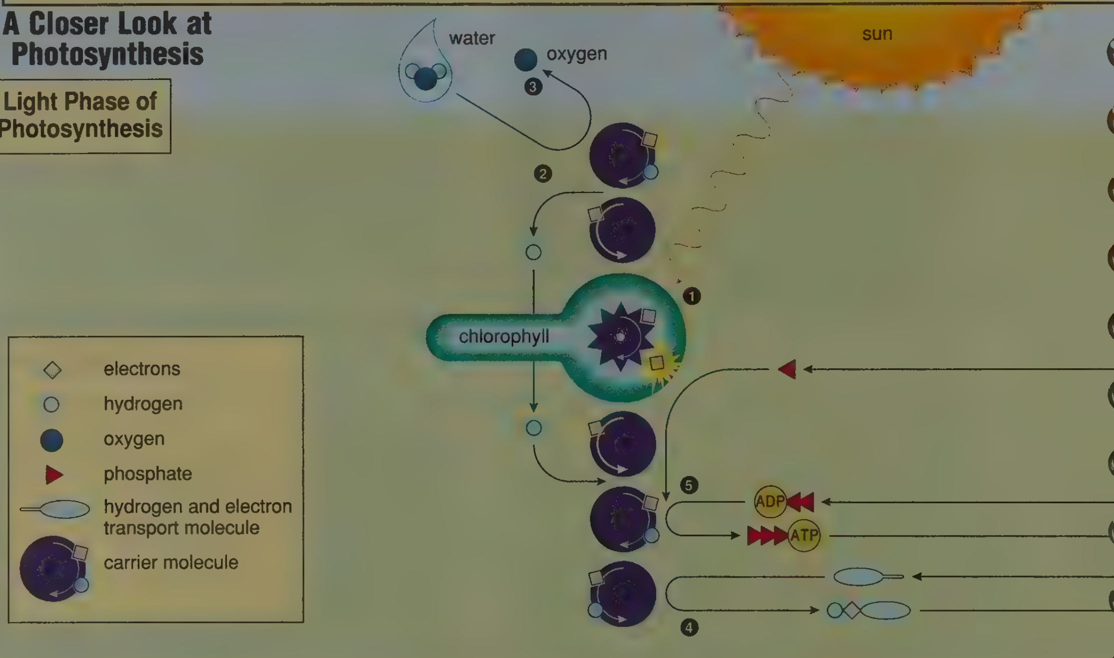
Experiments have revealed that photosynthesis actually occurs in two separate, yet closely related, steps. The first is called the **photo phase**, or *light reactions*, of photosynthesis. The photo phase takes place in the membranes of the grana of the chloroplast, where the chlorophyll and other necessary enzymes are. In the photo phase the light energy is absorbed and energizes a chlorophyll *a* molecule.

Energized chlorophyll *a* molecules use their energy to do two things: break apart water molecules and form ATP molecules from ADPs plus phosphates. The breaking apart of a water molecule by energized chlorophyll is called **photolysis*** (fo TAHL uh sis). The oxygen is released, and if cellular concentrations of oxygen become sufficiently high, the excess oxygen diffuses into the atmosphere. The hydrogen and some electrons from the water pass from one carrier molecule to another. As this happens, energy is released, allowing ATP to be made. The energy held in the ATP molecules as well as hydrogen and electrons will be needed in the second phase of photosynthesis.

The **dark phase**, or *dark reactions*, of photosynthesis takes place in the stroma of the chloroplast, where the necessary enzymes and products are located. The dark reactions may take place either in the dark or in the presence of light but require the products of the light reactions. When the photo phase stops, the dark reactions may continue for a short time, but soon they will run out of

A Closer Look at Photosynthesis

Light Phase of Photosynthesis



The Process of Photosynthesis

❶ *Chlorophyll absorbs light energy.* Light absorbed by chlorophylls and by other pigments is passed to chlorophyll *a*, which becomes *energized chlorophyll*. As energized chlorophyll releases its energy, it becomes normal chlorophyll.

❷ *Photolysis occurs.* Some of the energy from the energized chlorophyll is used to break apart a water molecule.

❸ *Oxygen is released.* The oxygen from the water molecule is released into the cytoplasm and is used, or it escapes into the environment. Two oxygen atoms combine, forming atmospheric oxygen (O_2).

❹ *Hydrogen and electrons are bonded.* Rather than diffusing out of the cell, hydrogen and electrons are passed from one carrier molecule to another. They will be used in the dark phase.

❺ *An ATP molecule is made.* Some of the energy from the energized chlorophyll molecule is used to manufacture an ATP molecule from an ADP plus a phosphate.

❻ *Carbon dioxide is fixed.* A carbon dioxide molecule which has diffused into the cell bonds to RuDP (ribulose diphosphate). RuDP is a five-carbon sugar with two phosphates bonded to it. The resulting six-carbon sugar is very unstable and

necessary materials. Because in the dark reactions carbon dioxide is combined with the products of the light reaction to synthesize glucose, the dark reactions are sometimes called the *synthetic phase.*

Note that all the products of the light phase are either used in the dark phase or given off. All the products of the dark phase either are end products of photosynthesis or are reused in the photo or dark phases. The dark phase of photosynthesis must therefore happen at the same time as the light phase. If the dark phase did not happen along with the photo phase, all the cell's transport molecules would soon have hydrogen and electrons attached to them, and photolysis would stop. The dark phase, however, can continue in the dark only as long as the products of the light phase are available. When all the hydrogen and electrons affixed to the hydrogen transport molecules have been used, the dark phase must stop until the light phase supplies it with more hydrogen and electrons.

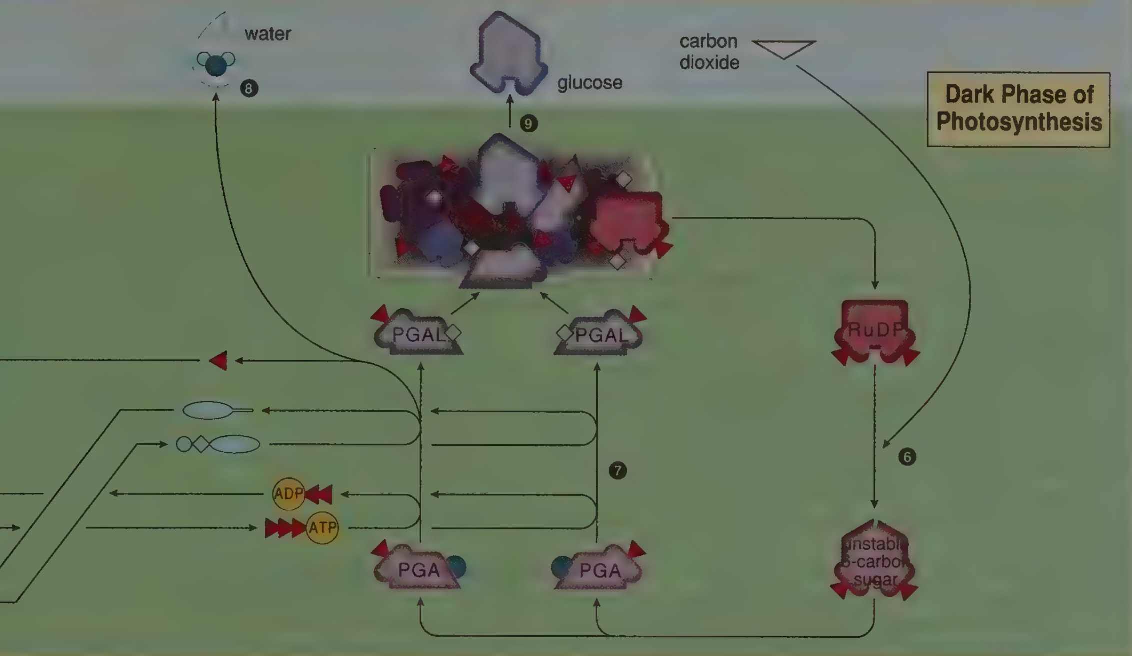
During the dark phase **PGA (phosphoglyceric acid)** accepts hydrogen and electrons and the energy and phosphate from an ATP molecule to form **PGAL (phosphoglyceraldehyde)**, which is the preliminary product of photosynthesis. Several PGALs combine to form glucose and **RuDP (ribulose diphosphate)**–the carbon dioxide-fixing molecule of the first of the dark phase. If the dark phase does not run, the cell soon runs short of RuDP. The entire process of photosynthesis must continue, or it must stop completely.

Visual 4A-2 can be used to present the phases of photosynthesis. Consider using permanent pens and adhesive sheets to color the visual. Then put the visual under a clear sheet and use other pens to draw lines or note important substances.

The dark phase is also called the Calvin-Benson cycle or carbon dioxide fixation cycle. There are other cycles that some plants can use under certain circumstances to make sugar.

Ribulose diphosphate is called ribulose biphosphate by some sources.

Dark Phase of Photosynthesis



breaks apart to form two molecules of PGA (phosphoglyceric acid). PGA is a three-carbon sugar with a phosphate attached to it.

❼ *PGA is converted to PGAL.* PGA is energized by the energy and a phosphate from an ATP molecule and then receives hydrogen and electrons from a transport molecule. Using these products of the photo phase, PGA forms PGAL (phosphoglyceraldehyde). The transport molecule and ADP released during the formation of PGAL may be used again in the photo phase.

❽ *Water is given off.* In the conversion of PGA to PGAL, a "new water" is released into the stroma.

❾ *PGAL is converted to glucose.* PGAL can be, and often is, used directly by the cell. PGAL, however, is not an efficient storage molecule. If PGAL ($C_3H_5O_3$~(P)) were doubled, it would need to obtain only two hydrogen atoms and to release two phosphates (indicated by the ~(P) in the formula) to be glucose. Actually, several PGAL molecules with hydrogen (from the light phase) combine, release phosphates, and thus form molecules of glucose and RuDP. The RuDP can then be used in the fixing of carbon dioxide as the dark phase begins again.

chemosynthesis: chemo- (chemistry or chemical) + -syn- (together) + -thesis (to place)

This box presents the concept that some organisms can make their own food using sources other than light. The material is supplemental but can be easily covered in most classes. The term **chemosynthesis** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

not absorb enough energy, chlorophyll *a* molecules cannot become energized enough to carry on photosynthesis. The cell must be able to absorb sufficient carbon dioxide. This is seldom a problem since carbon dioxide normally accounts for about 0.03% of the atmosphere by volume. A greenhouse with improper ventilation or with drastic temperature changes can affect the supply of carbon dioxide, and photosynthesis may cease.

Proper temperatures for photosynthesis vary from plant to plant. For most plants room temperature (21° C or 70° F) is about right. Above about 32° C (90° F), however, many of the plant's enzymes do not function properly for photosynthesis. In midday during hot summer months, many plants do not carry on photosynthesis. The lower temperature limit for photosynthesis is near freezing for some plants, but more moderate temperatures are required by others. In most plants the functioning of chlorophyll is temperature dependent.

Occasionally a lack of water will cause a plant to stop photosynthesis. On hot, dry summer days sufficient water may not be absorbed by the roots and transported up the stem to maintain photosynthesis in the leaves.

Chemosynthesis: Other Autotrophs

There are, however, a few bacteria that are capable of obtaining energy from inorganic chemicals they break apart, a process called **chemosynthesis*** (KEE moh SIN thih sis). These bacteria can then use that energy to synthesize sugar. Since chemosynthetic bacteria do not depend on other organisms for their food, they are autotrophs.

Chemosynthetic bacteria often grow in dark areas with little organic matter in their environment. Some of these bacteria change ammonia to nitrites and nitrites to nitrates; others use iron compounds. Probably the best-known chemosynthetic bacteria use sulfur compounds and produce sulfur dioxide. A walk through a swamp may disturb some collections of this gas that are trapped underwater. The rotten egg odor of sulfur dioxide that bubbles to the surface may have been produced by chemosynthetic bacteria.

Review Questions 4A-2

1. Describe chlorophyll *a* and tell its function. What colors of light does it absorb?
2. What are the functions of chlorophylls *b*, *c*, and *d*, and other plant pigments that do not carry on photosynthesis?
3. Write a chemical equation for photosynthesis.
4. What inputs are needed for and what products are made by the photophase of photosynthesis?
5. What inputs are needed for and what products are made by the dark phase of photosynthesis?
6. Tell the function in relation to photosynthesis of the following substances: chlorophyll, hydrogen and electron transport molecules, PGAL, and RuDP.
7. Tell how the photo and dark phases of photosynthesis are dependent upon each other.
8. Why is *the dark phase* a misleading name?
9. List the conditions necessary for photosynthesis.
10. What are the two types of autotrophs? List an example of each.

Cellular respiration is often shortened to *respiration*. Since respiration can mean many different things (e.g., breathing, oxidation of various substances), it is wise to use the term *cellular respiration* when referring to this process.

Cellular Respiration

You probably think of respiration as *breathing*–air being taken into and forced out of your lungs. Breathing is only the first step in your body's respiration. Oxygen obtained by breathing is transported to your cells where **cellular respiration** takes place. Cellular respiration is the breaking down of a food substance into usable cellular energy in the form of ATP. In most cells glucose

Answers–Review Questions 4A-2

1. Chlorophyll, a green pigment, has a head portion containing a single magnesium atom and a tail containing a carbon-hydrogen chain. It functions as a primary catalyst of photosynthesis and absorbs the violet and red wavelengths in the spectrum (see p. 92).
2. They absorb wavelengths not absorbed by chlorophyll *a* and transfer energy to chlorophyll *a* to be used in photosynthesis. The plant can then make use of more wavelengths in dim light.
3. $12\ H_2O + 6\ CO_2 + \text{light energy} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6\ H_2O + 6\ O_2 \uparrow$

*4. **(1)** Light phase input–light (energy), water; **(2)** Light phase products–oxygen (given off), hydrogen, electron (held by hydrogen and electron acceptor), and energy (held in ATP)

*5. **(1)** Dark phase inputs–hydrogen (from light phase), energy (from ATP), carbon dioxide; **(2)** Dark phase products–PGAL (or glucose)

*6. Chlorophyll catches light energy and uses it for photolysis and making ATP. Hydrogen and electron transport molecules catch hydrogen and electrons following photolysis and transfer them to the dark reactions. PGAL is the first product of the dark phase. RuDP is made as PGAL is made into glucose. RuDP is also the carbon dioxide acceptor in the dark phase.

*7. The products of the light phase are needed to run the dark phase, and some of the products of the dark phase are needed to run the light phase.

*8. The processes that happen in the dark phase can occur in the light or the dark. They are not dependent on light but are dependent on products from the light phase that are created only when light is supplied.

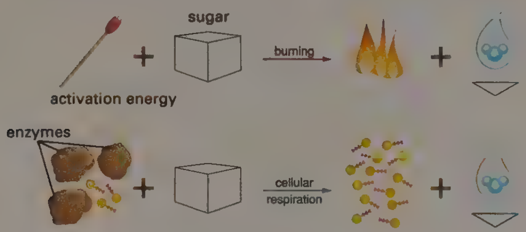
9. **(1)** Adequate supply of correct wavelengths of light; **(2)** cell's ability to absorb sufficient CO_2; **(3)** proper temper-

is the food substance; but lipids, other monosaccharides, and even proteins can be used.

Cellular respiration may be **aerobic*** (eh ROH bik) (requiring oxygen) or **anaerobic*** (AN uh ROH bik) (not requiring oxygen). Most cells carry on aerobic respiration. Many cells which normally carry on aerobic respiration can, when necessary, operate anaerobically. There are some bacteria and fungi which carry on only anaerobic respiration. We will discuss the primary aerobic cellular respirations first and then a couple of important anaerobic respirations.

Aerobic cellular respiration

Aerobic cellular respiration can be compared to burning. If you hold a lighted match to a sugar cube, the match will supply the activation energy necessary to set the sugar on fire. The burning sugar releases large amounts of energy as heat and light. Carbon dioxide and water vapor are also released, even though you cannot see them.



4A-5 *A comparison of burning and cellular respiration*

If you were to cover the flame in an airtight chamber, the fire would soon be extinguished because of a lack of oxygen.

In aerobic cellular respiration, the sugar glucose requires a small amount of activation energy to begin a series of enzyme-controlled chemical changes that release energy which is then trapped in ATP molecules. Carbon dioxide and water molecules are released in cellular respiration, as in burning. Cells cannot carry on aerobic respiration if they do not receive oxygen, and in time many will die.

Aerobic cellular respiration is the opposite of photosynthesis. Photosynthesis combines water, carbon dioxide, and light energy to form glucose. Aerobic cellular respiration breaks down glucose to form water, carbon dioxide, and energy. The materials which are needed for the one are the products of the other.

Photosynthesis can be generalized thus:

$$H_2O + CO_2 + \underset{\text{energy}}{\text{light}} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + O_2$$

Cellular respiration can be generalized thus:

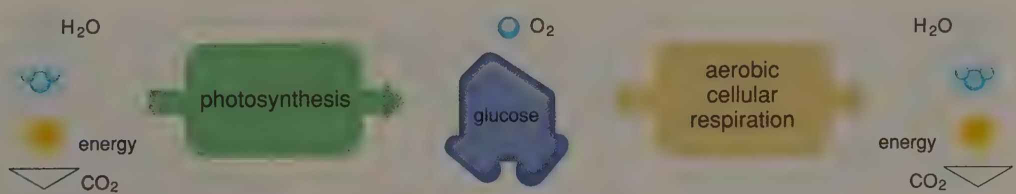
$$C_6H_{12}O_6 + O_2 \longrightarrow H_2O + CO_2 + \text{ATP (energy)}$$

These processes, however, are not the reverse of each other. For example, chlorophyll is not used in cellular respiration. Although some chemicals function in both processes, they proceed down different enzyme paths. These differences are necessary because the purposes of the two processes are different. Photosynthesis captures *light* energy and converts it to *stored chemical energy*. Respiration takes *stored chemical energy* and converts it to a *ready-to-use chemical energy* (ATP).

The light energy harnessed by a chlorophyll molecule during photosynthesis is made useful to all cellular processes by cellular respiration. The atoms of oxygen, carbon, and hydrogen are essentially the same after these processes, but the

aerobic: aero- (Gk. AER, air) + -bic (life)

anaerobic: an- (Gk. AN-, without) + -aero- (air) + -bic (life)



4A-6 *A comparison of photosynthesis and aerobic cellular respiration*

ature (21°C, or 70°F); **(4)** proper amount of water

*10. **(1)** Photosynthetic: plants, algae; **(2)** chemosynthetic: certain bacteria

*From a box.

glycolysis: glyco- (sweet) + -lysis (a loosening)

This box contains material that should be covered by advanced classes or advanced students. An average class can grasp the material, but it may require class time better spent on other topics. This material is common in standard high school biology texts and is frequently found on standardized tests.

The terms **glycolysis, citric acid cycle,** and **hydrogen and electron transport system** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

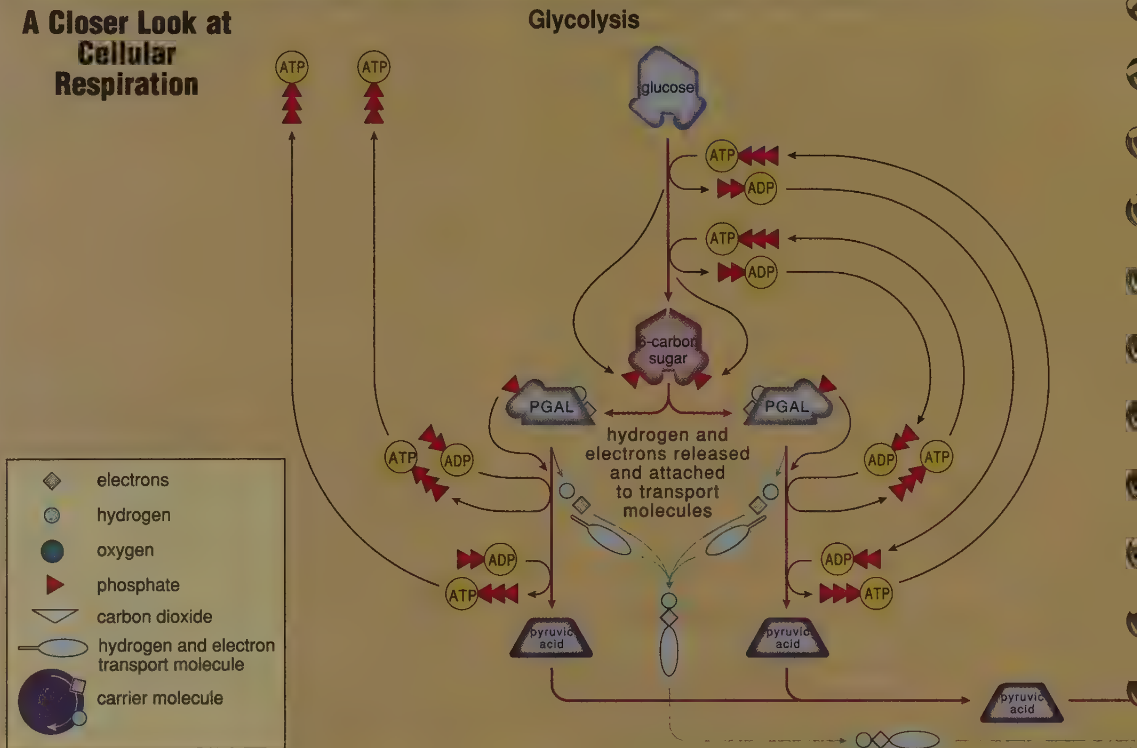
Visual 4A-4 can be used to present the process of aerobic cellular respiration. Consider using colored permanent pens and adhesive sheets to color the visual. Then put the visual under a clear sheet and use other pens to draw lines or mark important substances.

Aerobic cellular respiration can follow several different paths. Here we will look at the steps of the most common form of breaking down a glucose molecule to water, carbon dioxide, and ATP energy.

Aerobic cellular respiration can be divided into three phases. The first, called **glycolysis*** (glye KAHL uh sis), involves the breakdown of glucose to **pyruvic acid**. Glycolysis takes place in the cytoplasm, which contains the enzymes necessary for this series of reactions. Because glycolysis does not require oxygen, it is considered anaerobic. The products of glycolysis (pyruvic acid, hydrogen, and electrons) are shuttled to the mitochondria to continue aerobic cellular respiration.

The next two main steps in aerobic respiration of glucose are the **citric acid cycle (Krebs cycle)** and the **hydrogen and electron transport system.** Both of these processes happen in the mitochondria. The enzymes of the citric acid cycle are found in the fluid inside the inner membrane of the mitochon-

A Closer Look at Cellular Respiration



I. Glycolysis

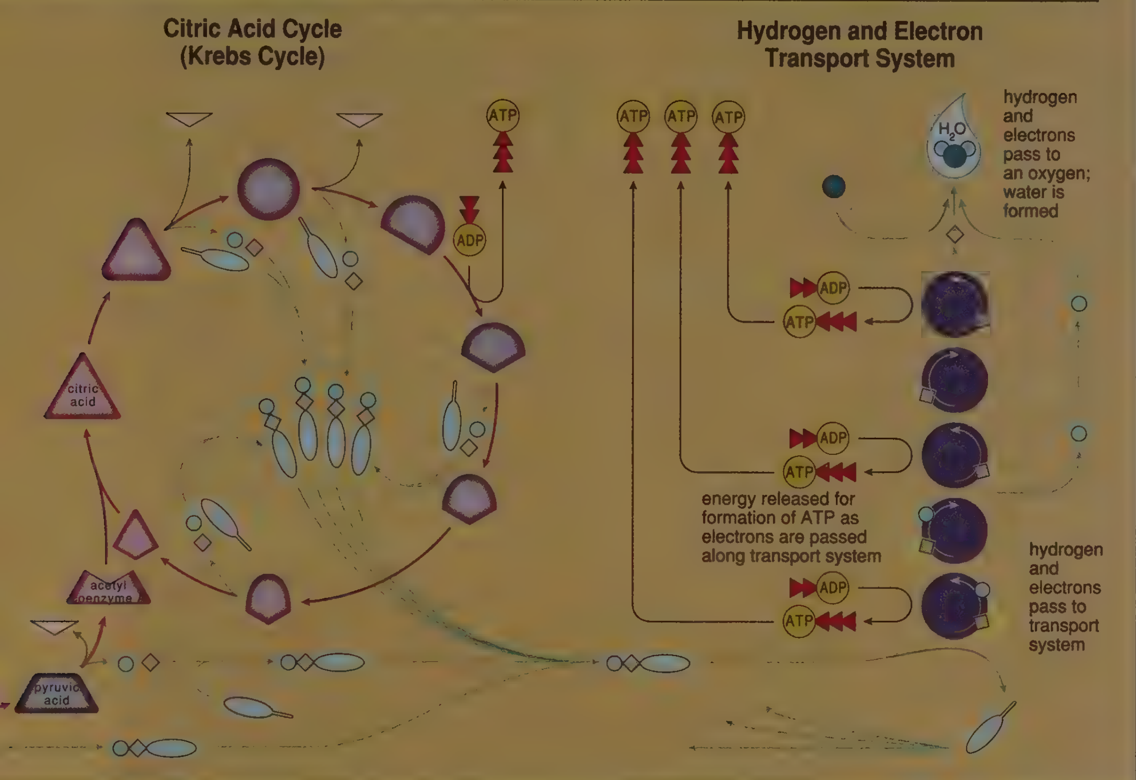
Two molecules of ATP supply the activation energy necessary to start glycolysis. After receiving energy and phosphates from ATP molecules, a six-carbon sugar splits into two molecules of PGAL. Each molecule of PGAL releases a hydrogen and two electrons (held temporarily by a transport molecule) and supplies the energy to form two ATP molecules. A total of four ATP molecules are made from the energy given off by the breakdown of one glucose molecule to two pyruvic acid molecules. Glycolysis, then, yields a net gain of two ATP molecules.

II. Citric Acid Cycle (Krebs Cycle)

The second stage of aerobic cellular respiration starts with pyruvic acid and converts it to acetyl coenzyme A (acetyl CoA). This process gives off carbon dioxide, hydrogen, and electrons. The carbon dioxide diffuses into the cell and, if concentrations in the cell become high enough, into the environment. The hydrogen and electrons are held temporarily by a transport molecule. Acetyl

dria. The enzymes of the hydrogen and electron transport system are part of the inner membrane of their mitochondria.

Both the citric acid cycle and the hydrogen and electron transport system are considered aerobic–that is, they require oxygen. Although the citric acid cycle reactions require no oxygen, the hydrogen and electron transport system does. If no oxygen is present, the final enzyme cannot release its electrons to receive the next set of electrons that comes down the system; thus the system stops operating. Without oxygen it does not take long for all the molecules in the transport system to have electrons attached to them, waiting to pass them on. If the transport system backs up, the hydrogen and electron transfer molecules in the cycle soon become filled. Without these acceptors, the citric acid cycle cannot operate. A lack of oxygen, then, eventually backs up both the hydrogen and electron transport system and the citric acid cycle. Since both processes ultimately require oxygen, they are aerobic.



coenzyme A is then converted to citric acid (one of the primary substances found in citrus fruits) and enters the citric acid cycle. This cycle is a series of enzymatically controlled steps that give off carbon dioxide, hydrogen and electrons (to a transport molecule), and sufficient energy to make an ATP molecule indirectly. The enzymes of the citric acid cycle are found in the mitochondria.

III. Hydrogen and Electron Transport System

The third step in aerobic cellular respiration is a transport system for hydrogen and electrons. The energy-containing transport molecules with their hydrogen and electrons received during glycolysis and the citric acid cycle enter this transport system. The hydrogen and electron transport system is a series of enzymes and carrier molecules bound to the membrane of the cristae of the mitochondria. As electrons pass from one enzyme to another, energy is lost. Occasionally, these energy losses are enough to form an ATP molecule. The final enzyme of the transport system allows oxygen, which diffuses from outside the cell, to combine with hydrogen and electrons to form water.

energy involved has been changed several times, and much of it has been lost.

ATP energy from a glucose molecule

The aerobic cellular respiration of glucose traps, in the form of ATP molecules, approximately 50-60% of the energy that was in the glucose molecule. Although a 40-50% loss of energy may seem wasteful, this breakdown of sugar is one of the most efficient energy processes known. In most manmade machines (cars, for example) only about 20% of the energy available in the fuel is used. Most of the rest radiates as heat.

Although glycolysis of 1 glucose molecule makes 4 ATP molecules, it takes 2 ATP molecules to start glycolysis. There is a net gain of only 2 ATP molecules. In the citric acid cycle, only 2 additional ATP molecules are formed for each glucose molecule. But the hydrogen and electron transport system forms 32 ATP molecules for every glucose molecule in cellular respiration.

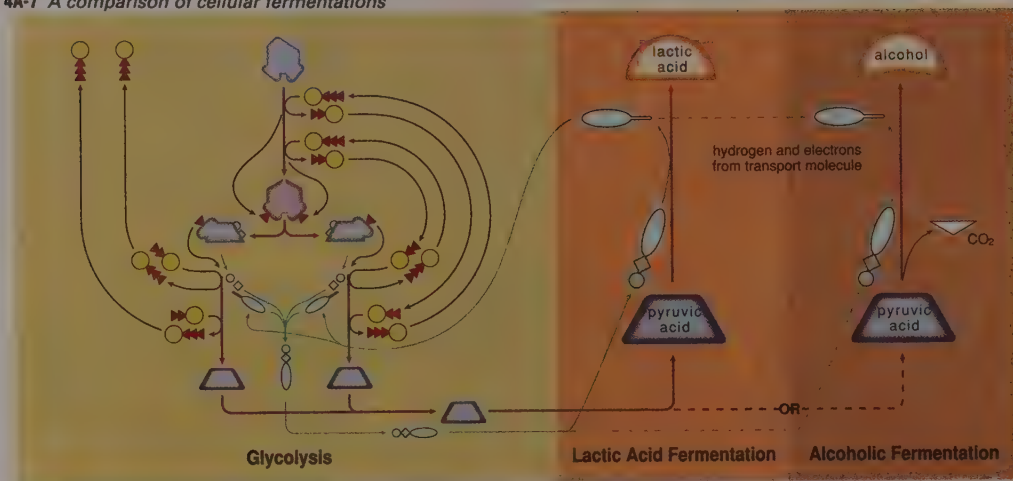
Cellular fermentation

Some cells exist in environments that do not have available oxygen. Many bacteria in the lower layers of swamps, lakes, or the ocean do not have oxygen available in their environment and are destroyed by exposure to free oxygen. Other cells which operate best with a supply of oxygen can occasionally operate without oxygen. For example, when you engage in strenuous physical activity, you may begin to breathe heavily but still be unable to supply enough oxygen for your muscle cells. Your muscles will then not carry on sufficient aerobic cellular respiration to supply the needed ATP. If cells in these circumstances are to supply themselves with usable cellular energy, they must carry on a type of cellular fermentation. **Cellular fermentation** is the breakdown of food (usually glucose) without oxygen.

Glycolysis in cellular fermentation is the same as in cellular respiration: one glucose is broken down to two pyruvic acid molecules. Depending upon the organism and the enzymes available, the pyruvic acid is usually converted to either alcohol or lactic acid.

In **alcoholic fermentation**, a pyruvic acid molecule gives off a carbon dioxide molecule; it then receives the hydrogen and electrons given off during glycolysis and forms an alcohol molecule. The use of the hydrogen and the electrons frees the transfer molecule so that it can be used again in glycolysis. This process is carried on by the bacteria used to make liquors and by the yeasts used in breads. Baking evaporates the alcohol of a bread dough, and the carbon dioxide causes the

4A-7 *A comparison of cellular fermentations*



There are several paths of cellular fermentation. Only the two most common have been dealt with here.

If the material on pages 98-99 was omitted, consider summarizing this diagram by telling the students that glycolysis is the first part (the anaerobic part) of aerobic cellular respiration.

This glycolysis is the same as on page 98.

Answers–Review Questions 4A-3

1. Cellular respiration is the breaking down of food substances into usable cellular energy (ATP). Breathing is only the first step in the body's respiration process. It supplies the necessary oxygen.
2. (1) Aerobic (requiring oxygen): most cells, both plant and animal; (2) anaerobic (not requiring oxygen): some bacteria and fungi
3. $C_6H_{12}O_6 + O_2 \rightarrow H_2O + CO_2 + ATP$ (energy)

*4. Glycolysis–the cytoplasm; citric acid cycle–fluid in mitochondria; hydrogen transport system–inner membrane of mitochondria (cristae)

*5. Glucose, appropriate enzymes, other factors such as ADP and P, and the energy of 2 ATPs are needed for glycolysis. Glycolysis produces a net of 2 ATP's worth of energy, two pyruvic acid molecules, and hydrogen and electrons (held by a transport molecule).

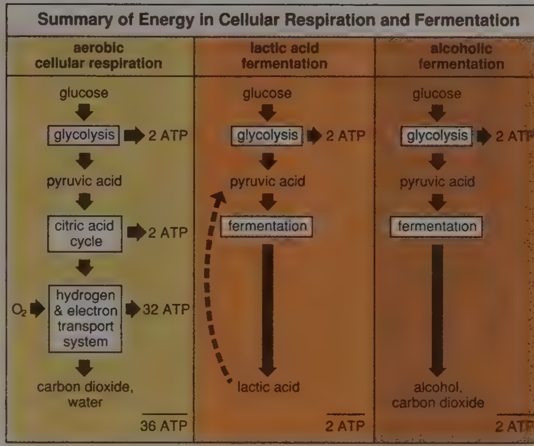
*6. The citric acid cycle requires pyruvic acid (acetyl CoA) and produces carbon dioxide, hydrogen and electrons (held by a transport molecule), and ATP.

*7. Hydrogen and oxygen are needed for the hydrogen and electron transport system. Water and ATP energy are the products.

*8. If the hydrogen and electron transport system has no oxygen available to it, the hydrogens and the electrons remain attached to the enzymes. When all the enzymes and the hydrogen and electron acceptors are full of hydrogens and electrons, the citric acid cycle cannot continue to give off hydrogen; so it too must stop. Since oxygen is needed for the hydrogen and electron transport system and the citric acid cycle cannot function if the hydrogen and electron transport system is not functioning, the citric acid cycle is considered aerobic.

dough to rise. Some plants can use this form of fermentation when necessary.

Lactic acid fermentation is used by some microorganisms (such as bacteria that form yogurt and cottage cheese) and, when necessary, by many animal cells. Pyruvic acid takes the hydrogen and electrons from glycolysis, freeing the transfer molecule. The resulting *lactic acid* contains much energy. When ample oxygen is available, some cells, especially in multicellular animals, have the ability to convert lactic acid back to pyruvic acid, which can then be used in aerobic cellular respiration. Cellular fermentation supplies no ATP energy beyond that obtained from glycolysis. Cellular fermentation, therefore, produces only a net gain of two ATP per glucose molecule.



4A-8

Stress the fact that 36 ATP molecules can be obtained from aerobic cellular respiration of a glucose molecule.

Stress the relative efficiency of these processes. This chart can also serve as a summary of the processes.

Visual 4A-5 can be used as a visual presentation or review of the energy supplied by aerobic cellular respiration and the two forms of cellular fermentation presented in the text.

Biological Terms

autotroph
heterotroph
ATP (adenosine triphosphate)
ADP (adenosine diphosphate)

Photosynthesis
photosynthesis
chlorophyll
photo phase
photolysis
dark phase
PGA (phosphoglyceric acid)
PGAL (phosphoglyceraldehyde)
RuDP (ribulose diphosphate)
chemosynthesis

Cellular Respiration
cellular respiration
aerobic
anaerobic
aerobic cellular respiration
glycolysis
pyruvic acid
citric acid cycle
hydrogen and electron transport system
cellular fermentation
alcoholic fermentation
lactic acid fermentation

Review Questions 4A-3

1. What is the difference between cellular respiration and breathing?
2. Name the two types of cellular respiration and list organisms that carry on each type.
3. Give a chemical equation for aerobic cellular respiration.
4. Where do each of the following occur: glycolysis, citric acid cycle, hydrogen and electron transport system?
5. What is required to activate glycolysis? What is produced by glycolysis?
6. What is required to activate and what is produced by the citric acid cycle?
7. What is required to activate the hydrogen and electron transport system? What is produced by the hydrogen and electron transport system?
8. Glycolysis is anaerobic because it does not require oxygen. The citric acid cycle does not require oxygen but is considered aerobic. Why?
9. List two forms of cellular fermentation. Give the beginning substances and the end products of each.

Thought Questions

1. Why must cells have a continual supply of energy?
2. Compare and contrast (a) photosynthesis and aerobic cellular respiration and (b) aerobic cellular respiration with alcoholic fermentation and with lactic acid fermentation.

9. **(1)** Alcoholic fermentation requires hydrogen and pyruvic acid to produce 2 CO_2 molecules and alcohol; **(2)** Lactic acid fermentation requires hydrogen and pyruvic acid to produce lactic acid, which some cells, in the presence of sufficient oxygen, can convert back to pyruvic acid to use in aerobic cellular respiration.

*From a box.

Answers–Thought Questions

1. Cellular processes that require energy occur continually.
2. **(a)**

Photosynthesis:	Aerobic Cellular Respiration:
• builds a glucose molecule	• breaks down a glucose molecule
• requires energy	• releases energy
• requires H_2O and CO_2	• releases H_2O and CO_2
• releases O_2	• requires O_2
• anabolism	• catabolism

The two processes are almost exact opposites.

(b) See Table 4A-8.

Process:	End Products:
• Aerobic cellular respiration	• CO_2, H_2O, 36 ATP
• Lactic acid fermentation	• lactic acid, 2 ATP
• Alcoholic fermentation	• alcohol, CO_2, 2 ATP

metabolism: meta- (Gk. META, change) + -bolism (BALLEIN, to throw)

Consider reviewing DNA and RNA structure, replication, and transcription as presented in Chapter 2B. Use the same visuals to orient students to this next step in the "story of inheritance."

Remind students that there are two kinds of proteins: enzymes and structural proteins. *Proteins* are what differ between cells of an organism and cells of different organisms, since lipids and carbohydrates are the same. (E.g., glucose is glucose no matter in which cell it is found. This does not mean that all cells have the same amount of glucose or that all carbohydrates are represented in all cells.) DNA is responsible for the different proteins.

Visual 4B-1, *A Comparison of the Codes of Language and Cellular DNA*, can be used to help students visualize the relationship between DNA and protein before going into a description of the process. Many students learn the process but do not understand what they know when they have learned it.

4B–Cellular Metabolism and Protein Synthesis

The **metabolism*** (muh TAB uh LIZ um) of an organism is the sum of all its life processes: photosynthesis, movement, respiration, growth, and everything else the organism does. Different organisms, of course, carry on different kinds and different quantities of the various metabolic pathways. For example, you are not able to carry on photosynthesis. The sugars you need to build carbohydrates are supplied by another metabolic pathway: digestion. Plants, on the other hand, do not carry on digestion to obtain sugars.

For years scientists have carefully studied cellular metabolic pathways. By understanding the chemical reactions, scientists hope to be able to correct metabolic problems that are either causing disease or environmental harm. For example, if scientists determine that a disease is caused by certain cells making too much of a chemical, they have a better chance of developing a treatment if they know how the cell makes that chemical. Suppose high temperatures and abundant nitrogen in a pond cause algae to make a chemical that kills fish. Scientists have a better idea of how to control the chemical manufacture if they understand the metabolic processes cells use to make it.

The understanding of cellular metabolism has permitted scientists to encourage certain processes that are profitable to us and to discourage those that are harmful. At one time scientists had hoped to greatly alter a cell's metabolic pathways, and even introduce different metabolisms to various cells. (Some people hope to save on their grocery bills by introducing photosynthetic metabolism to their children. The cosmetic effects, however, are not the only drawbacks to this scheme.) The cell's metabolism can be slightly altered, but major changes are prohibited by the complexities of, and the interrelations between, metabolic pathways in the organism and its cells.

Before discussing how some of the metabolic pathways relate to each other, we need to discuss what some scientists consider the most important one, the one which controls and permits all the others: protein synthesis.

Protein Synthesis

The discovery of how proteins are made was a major breakthrough in the understanding of life. An organism's ability to manufacture proteins enables it to carry on its life processes. Since what a cell can and cannot do depends upon its *enzymes,* cells are controlled by enzymes, which are proteins. In addition, almost every cellular and extracellular substance made by a cell is a *structural protein* or contains a structural protein.

The mechanism for protein manufacture needs to be exceptionally flexible, able to produce the several thousand different proteins found in every cell. But the process must also be stable. When the amino acids of a particular protein line up, they must be in the same sequence every time. If the sequence alters as much as one amino acid, the protein will often not function properly. Thus the process of protein synthesis must manufacture a vast number of different proteins, but it must also manufacture thousands of exact copies of these proteins.

A protein, you will recall, is a twisted and looped *polypeptide chain* of amino acids. Several of the amino acids in this chain may be bonded to other specific amino acids within the chain. Thus, proteins have a specific shape. Not all proteins are a single chain of amino acids. Some proteins are a bonding of several different amino acid chains. Lipids or carbohydrates or inorganic materials combine with some amino acid chains to form functional proteins.

The code of life

The sequence of the four bases found in cellular DNA determines the sequence of the approximately 20 different amino acids found in that cell's proteins. It is important that you understand the code before we discuss the mechanism responsible for the lineup of amino acids.

Do you realize that you speak in a code? Each word in our language is a symbol for something. The 26 letters of the alphabet make hundreds of thousands of different English words. The words

4B–Cellular Metabolism and Protein Synthesis

Notes–Chapter 4B

The unlocking of the genetic code in the 1960s was one of the most significant biological events ever accomplished by man. Although it did not immediately cure any disease or make life any easier, the potential was there because of this scientific breakthrough. Electricity may light the world and allow man to do great things; the internal combustion engine may provide man with locomotion. The ability to deal with the genetic code, however, gives man the potential to alter living things around him, even his physical self, in significant and permanent ways. This ability is already being used and will greatly affect future generations.

Genetic change is actually the topic of a later chapter. In order to understand genetic change, however, one must understand genetics. To understand genetics, one must understand the genetic code: how it operates and what it does. That is the topic of the first part of this chapter. Continue to remind students that this material will be more significant as they continue their study.

Stress the importance of understanding the concepts that proteins are made of a specific lineup of amino acids which is determined by the sequence of bases in DNA and that the DNA sequence of bases is inherited from other DNA. These concepts should be dealt with at the beginning and the end of this study. This material is essential not only to a thorough understanding of significant biological principles but also to biological points related to Christian ethics.

Some of the material in the second part of the chapter (especially the Facet on pages 105-6) is not usual for high school general biology texts. The interrelationships among metabolic pathways is relatively recently discovered material and requires a

express even more ideas when arranged into sentences.

The code of life uses the same basic format. The four bases–*adenine* (AD uh NEEN), *thymine* (THY MEEN), *guanine* (GWAH NEEN), and *cytosine* (SY toh seen)–can be called the alphabet of life. These "letters" are arranged in groups as "words" that may be interpreted as amino acids. All the "words" in the DNA code are 3 letters long. Three bases then become the code for a particular amino acid. The code of life, then, is formed of *triplets of bases* called **codons.** When many of these codons are in a particular sequence, they are read to form a chain of amino acids.

A series of words in a sentence has more meaning than just the words alone. The polypeptide chain of amino acids also becomes more than just a string of amino acids. It twists and bonds and combines with other amino acid chains or other substances to become functional proteins.

4B-1 Messenger RNA Codons for Amino Acids

first letter	second letter				third letter
	U	C	A	G	
U	phenylalanine	serine	tyrosine	cysteine	U
	phenylalanine	serine	tyrosine	cysteine	C
	leucine	serine	stop	stop	A
	leucine	serine	stop	tryptophan	G
C	leucine	proline	histidine	arginine	U
	leucine	proline	histidine	arginine	C
	leucine	proline	glutamine	arginine	A
	leucine	proline	glutamine	arginine	G
A	isoleucine	threonine	asparagine	serine	U
	isoleucine	threonine	asparagine	serine	C
	isoleucine	threonine	lysine	arginine	A
	(start) methionine	threonine	lysine	arginine	G
G	valine	alanine	aspartate	glycine	U
	valine	alanine	aspartate	glycine	C
	valine	alanine	glutamate	glycine	A
	valine	alanine	glutamate	glycine	G

The first base of the messenger RNA codon is found on the left, the second base in the middle, the third on the right. Thus, UGG codes for tryptophan, the only codon for that amino acid. Many codons code for the same amino acid. For example, GGU, GGC, GGA, and GGG all code for glycine. AUG, methionine, is the beginning amino acid and UAA or UAC or UGA is the last codon, indicating a stop of the polypeptide chain.

In DNA each of the 3 characters that make a word (codon) can be any one of the 4 letters representing the 4 bases. Therefore, the total number of possible combinations of 4 letters making a 3-letter codon is 64. Because there are about 20 amino acids, some amino acids are coded with more than one codon. There are some special codons believed to start and stop the process of lining up amino acids. You may consider them as punctuation marks in the DNA code.

Three types of RNA

Three different types of RNA are necessary to interpret the sequence of bases in a DNA molecule into the sequence of amino acids in a polypeptide chain. The first type is *messenger RNA.*

DNA, you may recall, is capable of manufacturing RNA by *transcription.* Transcription places the DNA code into the sequence of bases in an RNA molecule. (Recall that thymine in DNA is replaced by uracil in RNA.) The RNA molecule that contains the code for a polypeptide chain of amino acids is called **messenger RNA*** (mRNA). The mRNA carries the code from the DNA in the nucleus to the ribosomes in the cytoplasm, where the code is "read." The mRNA contains the proper sequence of codons to be interpreted as a chain of amino acids.

Amino acids are not assembled into proteins directly by the mRNA. Instead, the amino acids are attached to **transfer RNA** (tRNA) molecules, the second type of RNA. The tRNA molecules, about 80 nucleotides long, are formed in the nucleus. The chain of nucleotides forms several loops, taking a cloverleaf shape. At one loop of this configuration are 3 unattached bases called the **anticodon.** The anticodons will combine with the codons of the mRNA. If mRNA has the codon GAC, the tRNA that lines up on that codon will have the anticodon CUG. Anticodons, then, consist of bases which are the complements of the bases in the codon with which they align.

The free end of the cloverleaf stem of most tRNA molecules has the 3 nucleotide bases CCA. Using a high energy bond an amino acid attaches to the final base (adenine) of this sequence. The bonding of an amino acid to a tRNA requires the

Messenger RNA is also called *template RNA.*

If each base coded for an amino acid, there would not be enough codes for the number of different amino acids (4^1). If 2 bases were required, there would be only 16 choices (4^2). Three bases per amino acid (4^3) gives 64 possibilities, far more than the 20 plus needed.

The genetic code is virtually the same in all organisms studied thus far. Note that the genetic code in the above chart is in codons (mRNA). The anticodons (tRNA) would be the exact complements.

Visual 4B-2 can be used to discuss the various codons and amino acids possible for protein synthesis.

Stress the fact that the cell inherits its DNA. It does not decide which codes it will have; it was given those codes by its parent cell or cells. The DNA enables the cell to do many things, but it also limits the cell. Evolutionists tend to overlook the limitations.

That there are three types of RNA, one of which (rRNA) forms an organelle, is often confusing. Stress the different types before getting too far into the material.

certain level of understanding. To see the basic relationships as presented here is not difficult if the proper instruction has preceded it. If the students have grasped Chapters 3 and 4, they should have a basic understanding of the topic.

Objectives–Chapter 4B

- ❑ Describe the origin and function of messenger RNA, transfer RNA, and ribosomal RNA.
- ❑ List and describe the steps in the process of protein synthesis.
- ❑ Understand that protein synthesis is universal for cells but that the proteins synthesized are not the same for all cells.
- *❑ Compare and contrast various cellular metabolic processes.
- ❑ Describe how the various cellular processes are interrelated and interdependent when it comes to maintaining life.

*From a Facet.

One of the reasons for including this material has been to tie together and review the content of the previous sections. With the teaching of this material is an adequate opportunity to ask, "Now what is . . . and what does it need to work?" It is better to review while presenting new concepts than to review by "rehash" of the same old notes that were given before. The slower students will find it helpful to see the material in a different light, and the better student will appreciate not being bored by hearing it the same way. The additional terms and concepts in this section are easy if the students understand the review material.

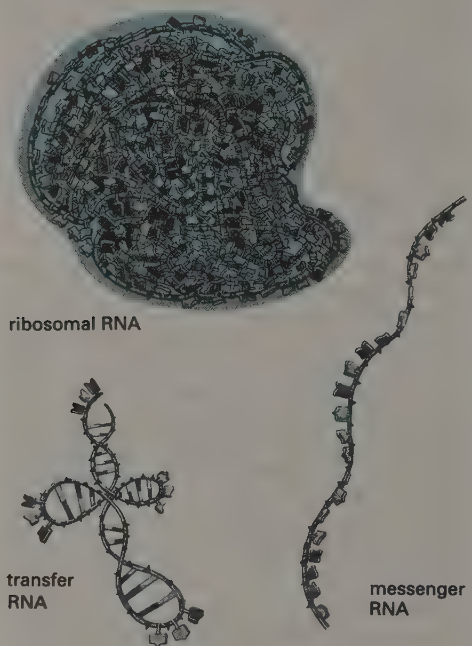
This box should be covered by advanced classes or advanced students. An average class can grasp the material, but it may require class time better spent on other topics. This box presents the existence of *exons* and *introns* and their possible significance. This material reinforces the concept of the "growth of scientific knowledge" and how scientific theories need to change as more is learned.

The terms **exon** and **intron** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Some poly-A tails are long; others are short. Introns and exons exist in many protein-manufacturing RNA segments of eucaryotic cells. The phenomenon may not be generally true of all mRNA formed by all cells.

energy of one ATP molecule. This energy is temporarily stored in the high energy bond. The particular amino acid which bonds to a specific tRNA molecule does not depend upon the final nucleotide bases, but upon different enzymes in the cytoplasm that bond each of the amino acids to the proper tRNA.

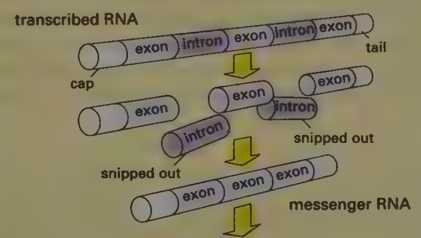
Ribosomal RNA (rRNA), the third type, is also manufactured by the DNA of the nucleus. The rRNA, however, does not come from the same area of a DNA molecule as does the mRNA. But rRNA combines with various proteins to form ribosomes. Some of the proteins located around rRNA are enzymes necessary for reading the codons of mRNA. Others proteins are enzymes for joining amino acids. Only at the point where mRNA is in contact with the ribosome are amino acids lined up to manufacture a polypeptide chain.



4B-2 *Three types of RNA*

The Manufacture of Messenger RNA

The mRNA was once believed to be a simple copy of one side of a DNA molecule. Today scientists believe the transcription process is only the first step. The RNA manufactured by transcription is actually longer than the number of nucleotides needed to code for the polypeptide chain of amino acids it produces. The transcribed RNA contains **exons** and **introns.** The *exons* are the sections of RNA that are actually needed in the mRNA. Exons are read as codons when making the protein. The *introns* are sections of transcribed RNA that must be cut out. They are not read when making the protein. Although the process is not completely understood, it appears



that introns are "snipped out" and the exons "glued" together as mRNA is formed.

During transcription an RNA *cap* is attached to one end of the mRNA. The cap is believed to deal with the mRNA lining up on the ribosome. On the other end a *poly-A tail* is attached. The tail is made of many adenine (poly-A) nucleotides. Scientists are not yet sure the function of the poly-A tail.

The discovery of exons and introns has opened up considerable speculation. Does it ever happen that an intron is kept? Are some exons ever left out? Does this result in different proteins? What might cause a cell to keep an intron it used to leave out, or leave out what once was an exon? Is this a possible form of natural genetic variation? Could this process cause additional genetic material needed by some cells as they spontaneously form cancer cells? Do exons and introns have anything to do with antibody formation and immunity? Do these RNA sections account for some of the protein differences seen in cells as they age? Only additional experimentation will tell.

Facet–Chapter 4B

It is suggested that this Facet be covered rapidly. Students should not be expected to memorize the fact that amino acids break apart to form two-carbon molecules that can make acetyl CoA and enter the citric acid cycle. It is important to see the interrelationships, understanding that these processes are able to exchange substances and products.

4B-1 **FACETS OF BIOLOGY**

Interrelated Metabolisms—Living Things Change Things

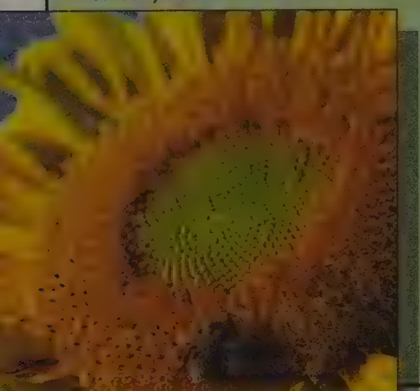
How often have you heard statements like "Eat your meat; you need the protein" or "Don't eat those french fries; they are loaded with fats" or "That soft drink is loaded with sugar, and no one needs extra sugar." All of these statements may be true, but they often lead to a false conclusion: fats are always fats, proteins are always proteins, and sugars are always carbohydrates. Such is not the case.

A quick, superficial glance, such as the one presented here, will likely cause the various cellular processes to appear distinct. They are not, however. The end products of the various cellular processes are related and can be changed from one to another.

Most cells also have the ability to transform substances within one process to another process. By the interrelationship of cellular processes, cells can change whatever organic substance they have in abundance into almost any other organic substance that they normally produce. This is essential for cells that do not have in their environment all the substances they need.

Plant cells, for example, produce abundant carbohydrates but obtain few or no lipids or proteins from their environment. Plants cannot eat and digest protein and lipid substances as humans do. They must, therefore, be able to convert the sugars they produce into the lipids and proteins necessary to form their cellular structures. Another example: humans do not have to eat fats to get fat (store excess lipids). One can eat too many carbohydrates and store the energy as lipids around the waist. (It is easier, however, to gain excess energy by eating lipids because fats have twice as much energy per unit of weight than carbohydrates.)

Plants produce carbohydrates by photosynthesis and manufacture the lipids and proteins they need from carbohydrates.



Carbohydrate and lipid metabolisms

One of the most important anabolic processes is *photosynthesis*, by which water, carbon dioxide, and energy are combined to form glucose. With the proper enzymes, glucose can easily be changed into other monosaccharides. With other enzymes monosaccharides can be converted into disaccharides, starches, cellulose, or any other natural carbohydrate. Some cells do not have the enzymes to make every one of these carbohydrate conversions because the cells do not normally require all the various carbohydrates. Cells usually have the enzymes necessary to convert the carbohydrates they have to the glucose and glucose back to the carbohydrates. One notable exception, however, is cellulose in plant cell walls. Once cellulose is made, most plant cells cannot break it down.

PGAL is the first stable product of photosynthesis, the build-up of sugar, and is also involved in *glycolysis*, the breakdown of sugar. PGAL can also be converted to *glycerol*, one of the components of most lipids. Through a series of steps, simple sugars can be converted into fatty acids. Most cells, therefore, can make carbohydrates into fats and fats into carbohydrates. If a human diet does not include sufficient fats, the liver can synthesize fats from carbohydrates. Fats, however, are not as easily converted to sugars. Generally this conversion occurs only when a person is dieting or starving.

Cellular respiration changes glucose and oxygen to water, carbon dioxide, and ATP energy. That is not all that cellular respiration does. Fatty acids can be synthesized from *acetyl* (uh SEET uhl) *coenzyme A* (acetyl CoA), and the reverse is also true: most cells can also break long fatty acid mol-

On page 548, the basal metabolic rate of humans is discussed.

This Facet presents that living things can convert most organic substances to other needed organic substances. The Facet is designed to be a major review of this chapter, while also introducing some minor concepts. It is suggested that this material be covered rapidly, stressing review, not the new material. No new terms are presented in this Facet.

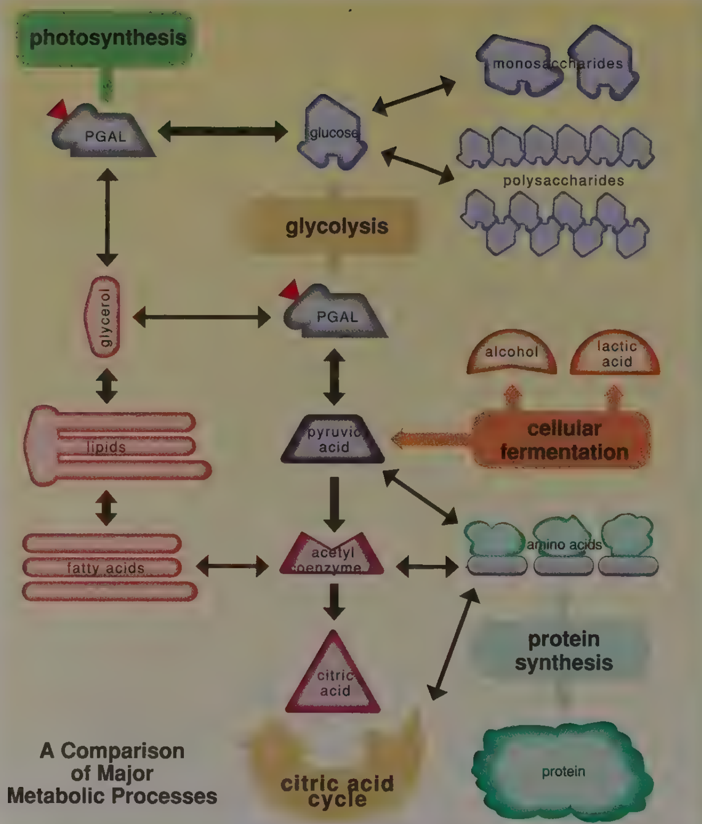
See photosynthesis (pp. 90-92); monosaccharides, disaccharides, starches, and cellulose (pp. 61-63); PGAL (pp. 95, 98); glycerol and fatty acids (pp. 63-64).

Most animals do not have the necessary enzymes to break down cellulose. Certain bacteria, fungi, and protozoans do manufacture these enzymes. Termites, for example, have a protozoan in their digestive system that produces the enzymes needed to digest the cellulose in wood (see p. 466).

In the chart, the large dark arrows indicate usual metabolic pathways. Light arrows indicate possible metabolic pathways. Colored blocks indicate processes that have been studied in Chapter 3 or 4.

See acetyl CoA (p. 99), citric acid (p. 99), and ATP (p. 91).

Visual 4B-3 can be used to review and compare the various cellular processes. Consider using permanent pens and adhesive sheets to color the visual. Then put the visual under a clear sheet and use other pens to draw lines or mark important substances which show the relationships between these processes.



A Comparison of Major Metabolic Processes

ecules into pieces of 2 carbons and then use these 2-carbon molecules to make an acetyl CoA that can be used in the *citric acid cycle.*

For each acetyl CoA entering the citric acid cycle, there is a net gain of 16 ATP molecules. An 18-carbon fatty acid can produce 128 ATP molecules by way of the citric acid cycle and the *hydrogen and electron transport system.* Using the same catabolisms, 18 carbons in the form of sugar (3 glucose molecules) can produce only 108 ATP molecules.

Protein metabolism

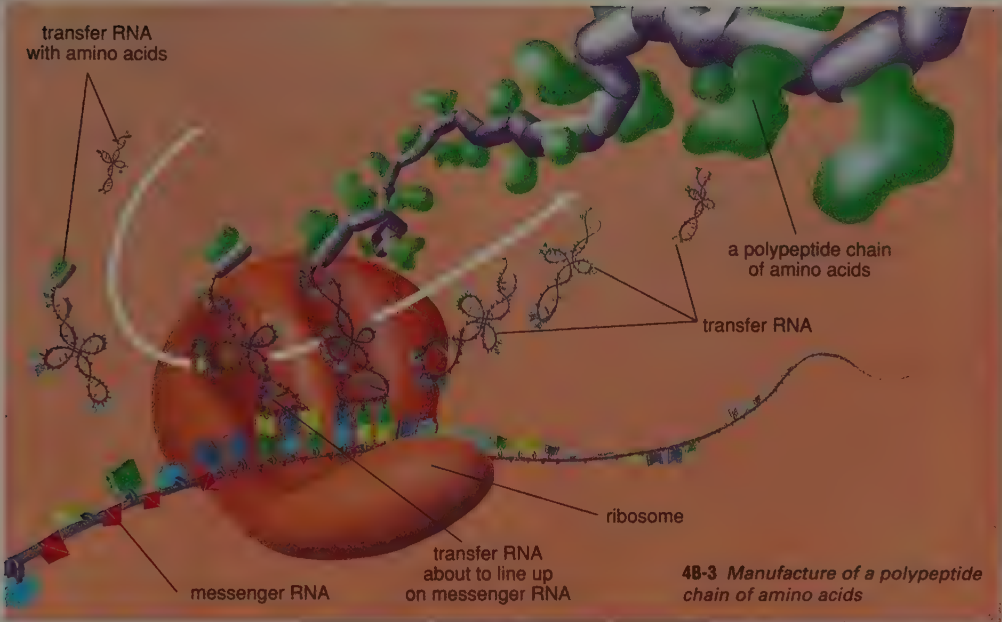
The amino acids necessary for protein synthesis may be obtained by digestion and absorption, or they may be manufactured by the cell. Certain amino acids can be made from substances at certain steps in the citric acid cycle, from pyruvic acid, or from acetyl CoA. Some organisms, however, cannot manufacture a few of the amino acids by these processes. These are called *essential amino acids* because organisms must obtain them. All organisms, however, do not require the same essential amino acids. Those that are essential for one organism may be easily synthesized by another.

Amino acids can also enter the citric acid cycle and be broken down to carbon dioxide, water, and ATP energy. Some amino acids can be converted to acetyl CoA or to pyruvic acid and then broken down as energy sources. Long before a person starves to death, his body will begin to convert proteins, including muscle proteins, into usable ATP energy. It is better to be thin, weak, and alive than it is to be muscular, strong, and dead from lack of energy.

Nucleic acid metabolism

Nucleic acids are formed of nucleotides. Usually a nucleotide can be used over and over again. As messenger RNA falls apart with use, its component nucleotides can be resynthesized into more RNA or DNA. If a cell is to grow and expand its protein-manufacturing abilities or if the cell is to replicate its DNA and divide to form two cells, it will need additional nucleotides. A nucleotide is composed of a sugar, a phosphate, and a nitrogen-containing base. The sugar can be supplied by carbohydrate metabolism. The phosphate is an inorganic substance which most cells absorb easily. The nitrogen-containing base is similar to some of the amino acids. A cell with the proper enzymes can synthesize nucleotides.

Review questions on page 108.



4B-3 *Manufacture of a polypeptide chain of amino acids*

If possible, use a prepared visual (or better yet, two or three) before you get to the text illustration. This will give the students ideas about the topic, and then the text illustration will be of more value. Using several visuals also teaches understanding rather than permitting the memorization of one picture. Test, using a different visual.

The manufacture of an amino acid chain

The mRNA leaves the nucleus with the DNA's triplet code by passing through a pore in the nuclear envelope. A ribosome lines up on one end of the mRNA. The ribosome has an active site which puts a mRNA codon at the proper place where a tRNA anticodon can line up with it. If the mRNA codon is AUG, a tRNA with the anticodon UAC will line up at that position. The tRNA has the amino acid methionine attached to its opposite end.

Once the codon and the anticodon have lined up, the ribosome moves down the mRNA, and the next codon is in place to be read. Suppose the next codon is UUU. The tRNA with anticodon AAA will join it, and the amino acid phenylalanine will now be right next to methionine, and they will bond together. Methionine and phenylalanine are now in the proper sequence for this polypeptide chain. Their sequence was dictated by the sequence of bases in the mRNA.

Ribosomal enzymes cause the amino acids lined up on the mRNA to form a peptide bond (see pages 64-65). The energy to form the bond holding the amino acids together was in the bond between the first amino acid, methionine, and the tRNA that brought it to the ribosome.

After the bonding of the amino acids (methionine to phenylalamine in our example), the first tRNA is no longer bonded to an amino acid. The tRNA that brought the first amino acid (which was temporarily bonded to the mRNA), leaves the ribosome and enters the cytoplasm as the ribosome slides down the mRNA to reach the next codon. (Soon another amino acid bonds with the tRNA, and it can be used again.) The process of reading new codons, bonding amino acids, and releasing empty tRNA's continues forming a polypeptide chain of amino acids.

The codon AUG, which codes for methionine, is called a *start codon.* Since methionine bonds on only one side it can start the polypeptide chain. Certain codons do not code for any amino acids. The codons UAA, UAG, and UGA are termed *stop codons* since they do not correspond to any amino acids and thus end the amino acid chain.

If a mRNA has many ribosomes on it, it is called a *polysome.*

Stress the complexity of a single protein. Then note that the DNA in every cell in a human body is capable of producing thousands upon thousands of different proteins.

Start codons are also called *initiator codons. Stop codons* are also called *terminator codons.*

Answers–Review Questions 4B-1 *(p. 108)*

1. **(1)** Alphabet–the four bases (A, T, G, C); **(2)** words–amino acid interpretation (codons); **(3)** sentence–polypeptide chains (proteins); **(4)** punctuation–start and stop codons

2. **(1)** Messenger RNA contains the code for a polypeptide chain; it carries the code from the DNA in the nucleus to ribosomes in the cytoplasm where mRNA is interpreted. **(2)** Transfer RNA, about 80 nucleotides long, is formed in the nucleus. It has one area of configuration of three unattached bases called the *anticodon,* which com-

This box should be covered by advanced classes or advanced students. An average class can grasp the material, but it may require class time better spent on other topics. This box presents that DNA exists outside the nucleus.

There are no terms in the box which are listed at the end of the chapter, but consider having students responsible for *mitochondrial DNA*.

DNA outside the nucleus, sometimes called cytoplasmic DNA, permits a cytoplasmic inheritance. It is not believed to be significant in the inheritance of many traits, but it is known to be essential in those few traits it does affect, like the function of mitochondria. Mitochondrial DNA and other cytoplasmic DNA would come only from the ovum, since the mitochondria in a sperm do not enter the zygote. Thus this genetic information is from only the female parent. Recent speculation regarding non-Biblical Eves (female apes who became mothers of humans) that has made its way into popular news media is based on this natural cytoplasmic genetic material. It has yet to be shown to be of major significance in inherited traits.

Some evolutionists have suggested that mitochondria were once procaryotic cells that got inside "early" eucaryotic cells and continued living there, dividing as the cells divided. To an evolutionist this may appear to explain ▶

Answers begin on page 107.

Ribosomes, then, start at a particular codon of the mRNA, travel along the mRNA, permitting the codons to be read by the lining up of tRNA with the appropriate amino acids, then end at a particular codon. The result is a polypeptide chain of amino acids which forms a protein. Occasionally a single mRNA may have several ribosomes all reading its messages at the same time. All evidence seems to indicate that a strand of mRNA is used repeatedly. When it breaks apart, the nucleotides may be used again to form more mRNA or any other nucleic acid.

One of the smaller proteins, ribonuclease (an enzyme which breaks apart RNA strands), is 124 amino acids long and is bonded in 4 places. The mRNA for this protein must be over 372 nucleotides long since each amino acid requires a codon of 3 bases. Most proteins, however, range from hundreds to thousands of amino acids long, requiring strands of mRNA with 3 times as many nucleotides.

Mitochondria–A Different Genetic Code

Not all of the genetic information found in a cell is located in the nucleus. Mitochondria have DNA, and organelles in other cells also appear to have DNA.

Mitochondrial DNA is a loop of DNA (similar to the DNA found in procaryotic cells) that manufactures RNA and appears to be responsible for the manufacture of some proteins used in the mitochondria. The code, however, is slightly different. UGA is usually a stop codon, but in the mitochondrial DNA of many organisms it is translated as the amino acid tryptophan. In plants, however, UGA is a stop codon in mitochondrial DNA.

New mitochondria are made in the cytoplasm by division of old mitochondria. In order to function each new mitochondrion must get a copy of the mitochondrial DNA. Mitochondrial DNA does not have the code for all the proteins needed for a mitochondrion to grow and reproduce and function. It must also have proteins made by the DNA of the nucleus.

Review Questions 4B-1

1. Compare the structures which make up the code of our language (letters, words, sentences, punctuation) to corresponding parts of the code of protein synthesis.
2. List the three types of RNA. Describe each and give its function.
3. What are exons and introns?
4. Describe the process of making a mRNA.
5. The following processes take place either in the nucleus, in the cytoplasm, or on the ribosome. Indicate where each process takes place.
   (a) transcription of a DNA molecule
   (b) reading of a mRNA molecule
   (c) lining up of a codon and an anticodon
   (d) replication of a DNA molecule
   (e) attachment of two amino acid molecules
   (f) attachment of a mRNA molecule to a ribosome
   (g) attachment of an amino acid to a tRNA molecule
6. What are start codons and stop codons?
7. Determine the codons and anticodons for the sequence of bases on the mRNA molecule given below. Then, using Table 4B-1, determine the sequence of amino acids in the section of a protein for which this mRNA would code:
   AUGUUCGUUAACGACCAAAUUUAA
8. Other than the nucleus, where is DNA located in eucaryotic cells?
9. What is unusual about mitochondrial DNA?

Facet 4B-1: Interrelated Metabolisms–Living Things Change Things, pages 105-6

1. Describe how carbohydrate and lipid metabolisms relate to each other.
2. How does protein metabolism relate to carbohydrate and lipid metabolisms?
3. Tell where the various components of a DNA nucleotide come from.

bines with codons of mRNA. The other end of tRNA has three nucleotide bases, CCA. Amino acids attach to the A base. **(3)** Ribosomal RNA combines with proteins to form ribosomes. Messenger RNA can be read because of the activity of some of the enzymes making up ribosomes. Amino acids are lined up to produce polypeptide chains only at the point where mRNA is in contact with a ribosome.

*3. An exon is a section of RNA that is kept and read to make a protein. An intron is a section of RNA that is cut out before the RNA is read to make a protein.

*4. A section of DNA is transcribed to form RNA. The introns are cut out and the exons put together. A cap and a poly-A tail are added as the mRNA is transcribed.

5. **(a)** Nucleus; **(b)** ribosome; **(c)** ribosome; **(d)** nucleus; **(e)** ribosome; **(f)** cytoplasm; **(g)** cytoplasm

6. **(1)** A start codon is found on mRNA and codes for an amino acid that bonds on only one side. This amino acid (methionine) starts a polypeptide chain (AUG). **(2)** A stop codon is the end of the chain of amino acids (UAA, UAG, UGA).

7. **(1)** Codons–AUG UUC GUU AAC GAC CAA AUU UAA; **(2)** anticodons–UAC AAG CAA UUG CUG GUU UAA AUU; **(3)** amino acids–methionine, phenylalanine, valine, asparagine, aspartate, glutamine, isoleucine

*8. Mitochondria (and occasionally some other organelles) have DNA.

*9. It is a loop of DNA. The codon UGA is not a stop codon; it codes for an amino acid.

*From a box.

Metabolism and Homeostasis

The functioning of an organism is its metabolism. When an organism functions to maintain a stable condition, its metabolism is causing its *homeostasis*. An organism does not constantly face exactly the same situation; so the metabolic activities of cells change to maintain homeostasis. For example, cells require ATP energy constantly. If the environment is favorable, the cell may grow rapidly and therefore use large quantities of energy to carry on the necessary processes to supply substances for growth. The same cell in an unfavorable environment will not grow but may still use the same amount of ATP to maintain its life. The metabolic rate under these two conditions will be the same. The homeostasis–that is, the steady state of life–will in each case be maintained, but the metabolic processes used will be different.

Metabolic rate

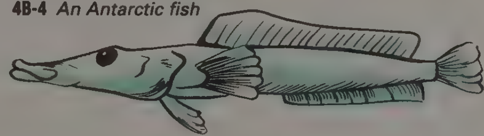
Some organisms have a higher *metabolic rate* than others. A rapidly growing young organism, be it a bacterial cell or a child, usually builds large quantities of substances and therefore has a higher metabolism than when it is mature and no longer growing. Plant cells in sunlight carry on photosynthesis and respiration, but in darkness it carries on only respiration. During the day, then, the rate of metabolism is higher.

Members of a school's athletic teams force their bodies to engage in higher metabolic activity than a person who spends most of his out-of-school time reclining in front of a television. But a young person can change his daily metabolic totals, and many do so as they participate in different activities. Rates of metabolism vary even during sleep. If one is sick and feverish, his metabolism will be higher as his body reacts to the disease. But resting metabolisms are not the same even among healthy people.

For some organisms the rate of metabolism depends on the environment. The amount of available light or water may determine the amount of photosynthesis. The presence or absence of certain vitamins (to serve as coenzymes) may affect one's health. Biological reactions seem to happen twice as fast for each increase of 10° C. Most enzymes of living systems, however, have optimal ranges. At higher or lower temperatures, they begin to function improperly rather than just faster or slower.

Increasing your internal temperature 10° C will kill you. The *desert pup fish* can exist from 10° to 40° C but does not function well at either extreme. Increasing a fish's body temperature will increase its metabolism, but there is a limit. The *Antarctic fish*, for example, flourishes in water from −2° to +2° C. As the temperature reaches 0° C, the fish is active. As the temperature rises, its metabolism slows down. At about +2° C it becomes immobile because of heat prostration. If temperatures continue to increase, the fish will die. God designed this fish for the constant near-freezing water temperatures of the Antarctic; so its metabolism is specialized.

4B-4 *An Antarctic fish*



Anabolism and Catabolism

Metabolism can be divided into two types:

- **anabolism*** (uh NAB uh LIZ um), those processes which build molecules and store energy, and
- **catabolism*** (kuh TAB uh LIZ um), those processes which break molecules down and release energy.

Many cellular processes involve both anabolism and catabolism, but there is usually a net gain or loss. To grow, for example, a cell must break some substances down in order to build others up. But in growth there is a net gain of molecules; so growth is usually referred to as anabolism.

The cell is an awesome chemical factory. Not only can it take raw materials and put together the substances it needs, but also it can take its own substances and re-form them when necessary. It can, within limits, change the course of its operations in keeping a constant supply of needed materials and in maintaining the internal homeostasis that permits its life. It is truly amazing what God has wrought in even the tiniest cell.

anabolism ana- (Gk. ANA, up) + -bolism (to throw)

catabolism cata- (down) + -bolism (to throw)

See homeostasis (pp. 83-84).

▶ mitochondrial DNA's existence. However, it does not explain many details about mitochondria: why are they so different in different cells–even different cells of the same organism? How did mitochondria get in *all* eucaryotic cells?

The evolutionist's explanation of mitochondrial DNA is both unnecessary and unacceptable to Biblical creationists. These evolutionists are biased in their explanation of a physical phenomenon (the existence of mitochondrial DNA). The only thing scientists can demonstrate is that mitochondrial DNA exists, what it is like, and how it functions. That is not enough information to justify any explanation of mitochondrial DNA's origin.

Answers–Facet 4B-1

1. Sugars can be converted into fatty acids. Most cells can make carbohydrates into lipids and vice versa. The body can produce lipids from carbohydrates if it needs them. Lipids are not as readily converted to sugars.
2. Amino acids enter the citric acid cycle and are broken down to CO_2, H_2O, and ATP. Some amino acids can be converted to acetyl CoA or pyruvic acid and broken down as energy sources. Deaminated amino acids may be converted to carbohydrates or fatty acids. Some amino acids can be synthesized from pyruvic acid, acetyl CoA, or products of the citric acid cycle.
3. The sugar of a nucleotide can be formed from a monosaccharide such as glucose. The phosphates are easily absorbed by most cells. The bases are similar to various amino acids and can be obtained from various parts of proteins.

Answers–Review Questions 4B-2 *(p. 110)*

1. Metabolism constantly changes according to changing body needs in order to maintain homeostasis, the steady state or condition of the body.
2. **(1)** Degree of activity; **(2)** age; **(3)** sleep; **(4)** health; **(5)** environment: quantity of light, water, vitamins, and temperature
3. **(1)** Anabolism–process which builds molecules and stores energy; **(2)** catabolism–process which breaks down molecules and releases energy

*4. **(1)** Intracellular digestion–Food is taken in by phagocytosis or pinocytosis

intracellular: intra- (L. INTRA, within) + -cellular (cell)

extracellular: extra- (L. EXTRA, outside) + -cellular (cell)

autophagy: auto- (self) + -phagy (to eat)

See phagocytosis and pinocytosis (pp. 78, 80).

Autophagy is essential to an organism's ability to change its structure as it matures or adapts to different conditions. This is *not* evolution, but a natural process of growth.

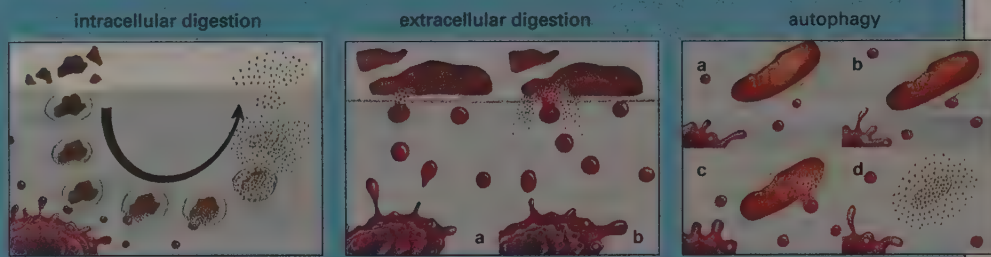
Autophagy is, in part, the process used to "eat" a tadpole's tail as the tadpole becomes a frog. It happens also in the atrophy of unused muscles.

Cellular Digestion

One of the important methods by which cells obtain substances is digestion. Many cells obtain materials for digestion by *phagocytosis* and *pinocytosis*. Those materials are then broken down by enzymes in **intracellular* digestion.** Enzymes, often supplied by lysosomes, break down the materials in food vacuoles to soluble carbohydrates, fatty acids, amino acids, salts, and other substances. These products of digestion diffuse through the vacuolar membrane into the cytoplasm and enter cellular processes.

Not all cells carry on digestion in food vacuoles. Some cells secrete enzymes which carry on **extracellular* digestion.** The soluble products of extracellular digestion are then absorbed by the cell. Most cells in multicellular organisms do not carry on digestion but rely on a supply of predigested food in their environment. The cells of your digestive system carry on extracellular digestion and supply the nutrients in a soluble form for all your body's cells.

Some cells carry on a "remodeling" process called **autophagy*** (aw TOHF uh jee). The cell forms a membrane around a damaged, worn out, or no longer needed cellular structure. Lysosomes join with the autophagic vacuole membrane and empty their enzymes into the vacuole. The cellular substances within the autophagic vacuole are then broken down to soluble materials which are absorbed into the cytoplasm. Substances in cellular structures can thus be recycled.



Biological Terms

metabolism

Protein Synthesis

codon

messenger RNA (mRNA)

transfer RNA (tRNA)

anticodon

ribosomal RNA (rRNA)

exon

intron

Metabolism and Homeostasis

anabolism

catabolism

intracellular digestion

extracellular digestion

autophagy

Review Questions 4B-2

1. Compare and contrast homeostasis and metabolism.
2. List several factors which may affect metabolic rates.
3. What are the two basic types of metabolism? Briefly describe each.
4. What are the two basic ways that cells can digest a substance?

Thought Questions

1. List several attributes which the process of protein synthesis must have. Explain why each attribute is necessary.
2. Since it is the proteins which make the differences between various organisms and individuals, discuss the possibility of DNA's being the genetic material.
3. For maturing into a frog, a tadpole relies heavily on the process of autophagy. Explain how this process is useful in the change in the frog's physical structures.
4. The interrelationship of the life processes (briefly outlined in this chapter) is carefully balanced while the organism is alive. Explain how this balance illustrates the first two laws of thermodynamics and the laws of conservation and degeneration.

Answers begin on page 109.

and digested in food vacuoles by lysosomes. The end products diffuse through cytoplasm. (2) Extracellular digestion–Food is digested outside the cell by secreted enzymes. The digested food is then absorbed by the cell.

*From a box.

Answers–Thought Questions

1. (1) Consistency–Each mRNA codon must code for the same amino acid. (2) Accuracy–The replication of DNA must be exact, or improper proteins may be formed. (3) Efficiency–The reactions must occur rapidly so that the necessary enzymes are continually produced.
2. DNA is, of course, the genetic material. DNA can make exact duplicates of itself which, if passed on to the next generation, can themselves pass on the ability to make specific proteins. Since proteins form the building blocks and enzymes essential to life, that which is able to code for the manufacture of various proteins is logically the genetic material.
3. In a tadpole, autophagy recycles the molecules that form the tail. These substances are then used in the necessary changes, such as the development of legs and lungs.
4. Various processes (metabolisms) break down some compounds, releasing energy and yielding components that can be used in other processes; organization is broken down, but the substance and energy are not lost (laws of thermodynamics). In any living organism, there are processes, such as protein synthesis, photosynthesis, and DNA replication, which result in growth, repair, and reproduction (conservation); there are other processes which result in aging, fatigue, and disease (degeneration).

GENETICS
THE CONTINUITY OF LIFE PART I

Facets:

FIVE

Time Frame
5A: 1-2 periods. The *Clones and Cloning* Facet can take 10 min. to $\frac{1}{2}$ period.

5B: 2-4 periods with both Facets.

Lab Activities
5A–*Mitosis and Meiosis* is about observation of the phases of mitosis. This lab could be done as a demonstration. The main exercise should take 1 period.

5B–*Genetics (Parts I-VI)* is a series of genetics problems which can be assigned to students to work outside of class. The students can then identify material they do not understand, and instruction can be adjusted accordingly.

5A–Genes and Chromosomes

Humans resemble one another. They usually have two eyes, two ears, a nose, and a mouth. Their hands are basically the same. Internal human features such as stomachs, livers, kidneys, and bones are about the same size, shape, and location in different humans. Even human cells have basic chemical and structural similarities. For example, most human cells have 46 chromosomes. Characteristics that every member of a species has are called **species characteristics.**

A brown-haired man with a blond-haired son is not unusual. The boy probably inherited his hair color from his mother rather than his father. But actually a child's hair color is determined by both parents. Characteristics such as eye, hair, and skin color; body build; intelligence; and other features that distinguish people are called **individual characteristics.** What you are depends in part on the species characteristics and in part on the individual characteristics that you inherit.

Have the students list the species and individual characteristics for an animal. Have them note that individual characteristics are natural variations, which one would expect to find. These variations are limited (see p. 153).

5–The Continuity of Life Part I: Genetics

The study of genetics is not an easy one. It is true that some students grasp the basic concepts of DNA, genes, Punnett squares, and possible gamete combinations quite readily. They even become adept at figuring out pedigrees. Other students do not grasp these at all. The next chapter, however, presents nondisjunction, crossing over, mutations, and various other concepts which are as basic but not as simple. Even geneticists often have to admit that they do not really understand these subjects.

The difficulty of this material, however, is not justification for skipping it. After all, it is in the area of genetics that biological evolution is clearly refuted on a scientific basis. This will be the basic thrust of the end of Chapter 7 which deals with evolution. Only when one has a firm grasp of genetics can he see how truly absurd some material cited to support evolution really is. In the biological realm genetics illustrates the law of conservation most clearly. In order to understand these points, a person must have a basic understanding of this chapter and the first part of the next chapter.

Some of the most significant issues of genetics are dealt with in the final section of the next chapter: genetic engineering and eugenics. One cannot truly understand genetic engineering and eugenics without a basic understanding of the mechanisms of genetics presented in this chapter. It is reasonable to assume that the current strides made in genetics will continue. Christians can expect more and more difficult questions regarding what is right and wrong–questions similar to those posed in the next chapter.

What does all this have to do with Mendel's peas, Punnett squares, and Queen Victoria's hemophiliac offspring? In the Chris-

One Scripture misapplied to support the preformationist view is, "For as in Adam all die" (I Cor. 15:22).

Secular humanism seeks to ignore man's spiritual condition as a determining factor of humanity. Humanism states that an individual is shaped only by heredity and environment. Improve either or both, and the individual or race is improved. A person's spiritual condition, however, cannot be ignored. It is the most important factor in view of eternity. However, Christians often emphasize the spiritual to the exclusion of the other two. This is also an unrealistic imbalance.

Did you inherit *all* your characteristics from your parents? Do the hundreds of thousands of genes you inherited so control you that you just mechanically live out what you inherited? Both questions must be answered yes and no. Your genes determine your species characteristics and individual characteristics. But the *extent* to which these characteristics can express themselves in many ways depends upon your *environment*, the second major physical factor that determines what you are. For example, if a person inherited genes for being over six feet tall but had a poor diet, insufficient rest, and little exercise as he matured, he would likely not reach his genetic potential. This happens often in underdeveloped countries. Intelligence potential, most geneticists believe, is also inherited. If an individual's environment gives little stimulation, though, his intellect will not become what it could be.

As a human you are more than just the sum of your inherited genetic potential and your environment. You have a spiritual nature, a soul that will live forever. Your spirit, if permitted to remain in Satan's control, uses your inherited physical traits and your environment to sin and glorify the Devil. If, however, you are saved by Jesus Christ, you are born into the heavenly family. If your will is yielded to God, He will direct your environment and use your genetic potential to develop in you the fruit of the Spirit and to glorify Himself (Rom. 8:28; Phil. 4:13).

The Mechanism of Heredity

Genetics, the study of heredity, is both one of the oldest and one of the newest of the biological sciences. In the Old Testament the Jews were commanded, "Thou shalt not let thy cattle gender [mate to produce offspring] with a diverse kind" (Lev. 19:19). This type of selective breeding, which has been engaged in for thousands of years is, in essence, practical genetics.

Men have always been interested in how the characteristics of one generation are passed on to the next. The ancient Greeks believed that each offspring was a mixture of elements from the parents' bodies. Aristotle proposed the *particulate theory* of reproduction: particles of the parents' blood mix and then join to form the offspring. From this belief came the terms "pure blood" and "blood relative."

A later group of people, called *preformationists*, believed that there were little, completely formed organisms in the sperm which merely grew up when planted in the egg. One early microscopist actually reported having seen tiny people in human sperm. Most preformationists also believed that inside the tiny person in that sperm are other sperm which contain smaller people, which contain sperm with even smaller people *ad infinitum*. In other words, inside Adam was *all* mankind, just waiting to grow up.* The impossibility of such decreasingly tiny people was part of the "miracle" of reproduction.

In the middle of the 1800s Gregor Mendel, who will be discussed later, performed a series of experiments with garden peas. Mendel advanced the understanding of genetics by proposing that there are pairs of *factors* in organisms and each parent gives a single set of these factors to its offspring.

Mendel's report collected dust in libraries until the early 1900s, when it was rediscovered. By that time microscopy had advanced beyond the blood particle and preformation theories. Mendel's theories were applied to the new cellular knowledge as modern theories of genetics began to take shape.

In 1953 Watson and Crick described the DNA molecule, which was determined to be the genetic material. From the years 1953 to 1963 the amount

5A-1 *A drawing of a human sperm by a preformationist. Preformationists cited Scripture out of context to support their theory.*

tian classroom the relationship is significant. A teacher cannot tell the student what is wrong with genetic engineering because the future of genetic engineering is not certain at this point. Some methods, as long as they are not mandatory, may be acceptable for Christians. Perhaps other methods must be condemned.

Education's meaning or significance is to prepare the learner to face the problems of life. Education must equip him not only to solve problems, such as assembling a bicycle according to written instructions, but also to make decisions even when they involve unknown factors. Major genetic questions will arise, questions for which most Christian high school biology teachers (even research scientists, physicians, and fundamental Christian pastors) do not have the answers. These leaders still have a responsibility to equip their charges, as much as possible, to arrive at the Scriptural answers they will need when the time comes.

Pastors prepare their flocks to make future decisions by preaching "the whole counsel of God." Biology teachers have an obligation to present material within the framework of the courses that can equip young Christians to make decisions regarding genetics. We do this by presenting the foundational concepts (e.g., DNA, chromosomes, fertilization, Mendelian genetics) in such a way that they do not appear to be deep, dark, incomprehensible secrets, but rather scientific knowledge. This opens the door to present principles such as the sanctity of human life which, when applied to the scientific knowledge, will serve as the foundation needed to arrive at the proper Scriptural decision.

5A–Genes and Chromosomes

Notes–Chapter 5A

The study of mitosis and meiosis can be very boring. Students may be able to list the phases of mitosis and tell in what conditions a chromosome is in each phase, but often they still have a "So what?" attitude.

of known genetic information doubled. Today genetic knowledge doubles in less than two years. Truly, man is now in the Genetic Age.

> **Characteristics of a Gene**
>
> For years before scientists had determined what a gene was, they knew the characteristics it must have. Consider these characteristics of a gene.
>
> ❑ Genes are fundamentally identical in both kinds and amount in the cells of an organism. For example, virtually all of your cells have the same number and kinds of genes.
>
> ❑ Genes are fundamentally identical in both kinds and amount in the cells of each organism of a species. For example, a normal human has the same number and kinds of genes as other normal humans.
>
> ❑ Genes are chemicals which can function as individual units–that is, they are different chemicals, each of which can do a different thing.
>
> ❑ Genes are able to carry information for the formation of organic chemicals–that is, they are responsible for biosynthesis.
>
> ❑ Genes are able to reproduce themselves–that is, they are able to make copies of the information they have.
>
> ❑ Genes are able to be passed on to the next generation.
>
> ❑ Genes are found in the cell's nuclear material.
>
> The *nucleic acids* (DNA and RNA) are the only substances known to possess all of these characteristics.

Genes

The common term *gene* is hard to define. Mendel called the pairs of particles involved in passing on inherited characteristics *factors;* today we call them genes. But what is a gene?

Scientists now define a **gene** as a section of DNA that produces a particular polypeptide chain of amino acids (a protein or a section of protein) and thereby causes a trait. Not all traits are as visible and discernible as blue eyes or brown hair. Many genes produce structural or enzymatic proteins which perform functions that you do not see. The enzymes of the citric-acid cycle, for example, are traits for which your genes have the code. If at conception you had lacked these genes, you would not be alive.

Some people find it hard to believe that genes carry all the information needed to produce the physical traits you possess. Your DNA is tightly compressed; the DNA from all your cells would fit into a 1-inch cube. But if all the DNA in one human cell were uncoiled and stretched out, it would form a thin string about 2 yards long. Some believe that the information found in the DNA of *one* human cell is equal to the information in 1,000 books containing 600 pages each. The nucleus of one human cell is a huge library of chemicals.

Chromosomes

Mendel had envisioned the factors floating around somewhere inside the organism. In fact they do not. Your genes are not even floating around independently inside the nuclei of cells. Each DNA strand in a nucleus actually comprises many genes. These long strands of DNA are associated with proteins and are called **chromosomes.** The proteins help to support and protect the long, thin strands of DNA and also help in DNA *replication* or in *transcription* of RNA.

In an active, nondividing cell most of the chromosomes appear as a fuzzy, tangled mass in the nucleus called the *chromatin material*. Some of the genes are active, producing RNA. Others are not being used and are often tightly coiled.

The number of chromosomes in a cell is a species characteristic. Humans have 46 chromosomes in the nuclei of most of their cells. Fruit flies have 8; certain species of goldfish have 100; crayfish have 200. Do not get the idea that the number of chromosomes determines the species. It is the genes on the chromosomes that make the organism. But every normal cell in a particular organism, as well as every normal organism of that type, has the same number of chromosomes.

Review Questions 5A-1

1. What are the three factors that contribute to the make-up of an individual?
2. List (a) several species characteristics and (b) several individual characteristics of dogs.
3. List seven characteristics a gene must possess.

Consider briefly presenting the characteristics of genes here, at the beginning of the study of heredity. Return to this list as a review at the end of Chapters 5B and 6A, when the terms will make more sense and be more valuable.

Proteins were once thought to coat the DNA of a chromosome. Scientists now believe that some sections of DNA are wrapped around proteins.

The DNA found in virtually all human cells is identical; an individual has the same amount and kind as any other human. DNA is a chemical which carries the information needed to make a protein, and different DNAs make different proteins. DNA is capable of replication, is found in the nuclear area of each cell, and is able to be passed on to the next generation of cells.

Visual 5A-1 can be used to present the characteristics of genes now and as the gene concept is developed. Suggestions regarding when to return to this list of gene characteristics can be found in the teacher's notes on the following pages.

Answers begin on page 114.

This is the result of two instructional errors: stress on simply memorizing content for the test and lack of stress on the significance of the material.

Students do need to know the steps and happenings during mitosis and meiosis. The challenge is to present these processes in such a way and within such a framework that it is worth remembering. This is best done by stressing *why* mitosis and meiosis are necessary, *what happens* if the processes don't work, and *how* these processes are everyday happenings.

In this chapter much space is spent dealing with the significance (the whys) of mitosis and meiosis. These processes are crucial to a workable understanding of genetics and genetic engineering and its capabilities. Only when the biology is understood can the proper Biblical principles be applied to problematic areas.

Facet–Chapter 5A

The Facet in this chapter is significant. Cloning is a much misunderstood topic. Many people falsely approach it as science fiction or futuristic. Cloning is an old science which is quite valuable in agriculture. It is also an area in which scientists are rapidly learning new techniques. Some of these new techniques, however, create potentially significant spiritual problems. Some of these concerns are briefly presented and discussed in this Facet.

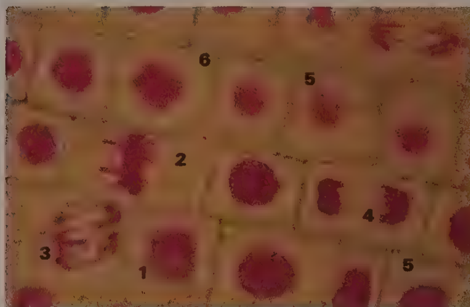
Consider using this Facet to promote interest in the present material and that which is to follow. Some teachers may be tempted to shy away from this material because it deals with content with which they are not familiar, and they do not have a "chapter and verse" that neatly applies to various spiritual concerns which will be discussed in more detail later. Difficulty of subject matter should not be a reason for skipping material. The present and future value to the learner should be the factor which determines the inclusion or omission of the material.

cytokinesis: cyto- (cell) + -kinesis (to move)

Mitosis

When a cell divides, it is not essential that an equal amount of cytoplasm and an equal number of organelles be in each of the new cells. If the new cell has a complete set of genes, it can manufacture what is missing. The division of the nuclear material in such a way that each new nucleus has a complete identical copy of the genetic information from the parent cell is called **mitosis** (mye TOH sis).

This photograph can also be used to show stages of mitosis in plant cells: (1) prophase, (2) metaphase, (3) anaphase, (4) telophase, (5) daughter cells, (6) interphase. Ask the students to find the phases.



5A-2 *Cells dividing in onion root tips. The chromosomes are the dark masses in the center of each cell. All the phases of mitosis are illustrated. Can you find them?*

Scientists have divided the *process* of mitosis into phases:

Interphase is frequently divided into phases: G_1, the gap (interval) before DNA replication; *S*, synthesis of DNA (replication); and G_2 a second gap before mitosis.

❑ **Interphase** The period of time between cellular divisions–interphase–is not actually a phase of mitosis. The cell carries on normal metabolism. The double *centriole* is just outside the nucleus. Inside the nucleus the chromatin material is producing RNA. Toward the end of interphase all the chromosomes are completely replicated. These DNA duplicates are attached to one another by the **centromere.** Each DNA duplicate is called a **sister chromatid.** The fuzzy appearance of the chromatin material hides these structures during interphase. A cell that is ready to begin mitosis is called a **mother cell.**

Be sure to note the variations in mitosis; the animal cell mitosis just studied is typical, but mitosis in different cells, especially those with cell walls, differs slightly.

❑ **Prophase** The first phase of mitosis is prophase, during which the centrioles divide and migrate to opposite sides of the nucleus. Around each centriole the **aster** becomes prominent. Some of the aster fibers form the **spindle** between the centrioles. The nuclear chromosomes get short and thick as they coil up, becoming visible as individual chromosomes composed of two sister chromatids that are pinched together at the site of the centromere. The nuclear membrane disintegrates, and the nucleolus disappears.

❑ **Metaphase** At the end of prophase the chromosomes (sister chromatid pairs) migrate to the center of the spindle. Metaphase is the stage when the centromeres are on the *equatorial plane*–the imaginary line at the middle of the spindle. During metaphase the sister chromatids appear to repel each other, taking the shape of an "X."

❑ **Anaphase** Metaphase ends as the centromeres separate. Anaphase is the period of time during which the centromeres appear to pull the **daughter chromosomes** (separated sister chromatids) along the spindle fibers toward opposite poles.

❑ **Telophase** When the daughter chromosomes reach the end of the spindle, telophase begins. At each centriole a new nucleus begins to form. The daughter chromosomes begin to uncoil, the nucleoli reappear, and the nuclear membranes reform. The spindle disappears, leaving only a small aster around each centriole. The plasma membrane constricts at the center of the cell, and the cytoplasm divides, a process called **cytokinesis*** (SYE toh kih NEE sis).

❑ **Daughter cells** The two cells resulting from mitosis (followed by cytokinesis) are daughter cells. Daughter cells are actually cells entering interphase.

Under normal conditions, daughter cells get a copy of the mother cell's DNA with exactly the same genes as the mother cell and have the same genetic potential.

Variations of mitosis

Not all cells go through mitosis in the same way. Figure 5A-3 shows the cytokinesis of animal cells. Animal cells *invaginate* (in VAJ uh NATE) (pinch in). Plant cells, because of their cell walls, cannot invaginate. Rather, they form a *division plate* near the equatorial plane of the spindle. The division plate, made of two cell membranes separated by a primary cell wall, begins to form in

Objectives–Chapter 5A

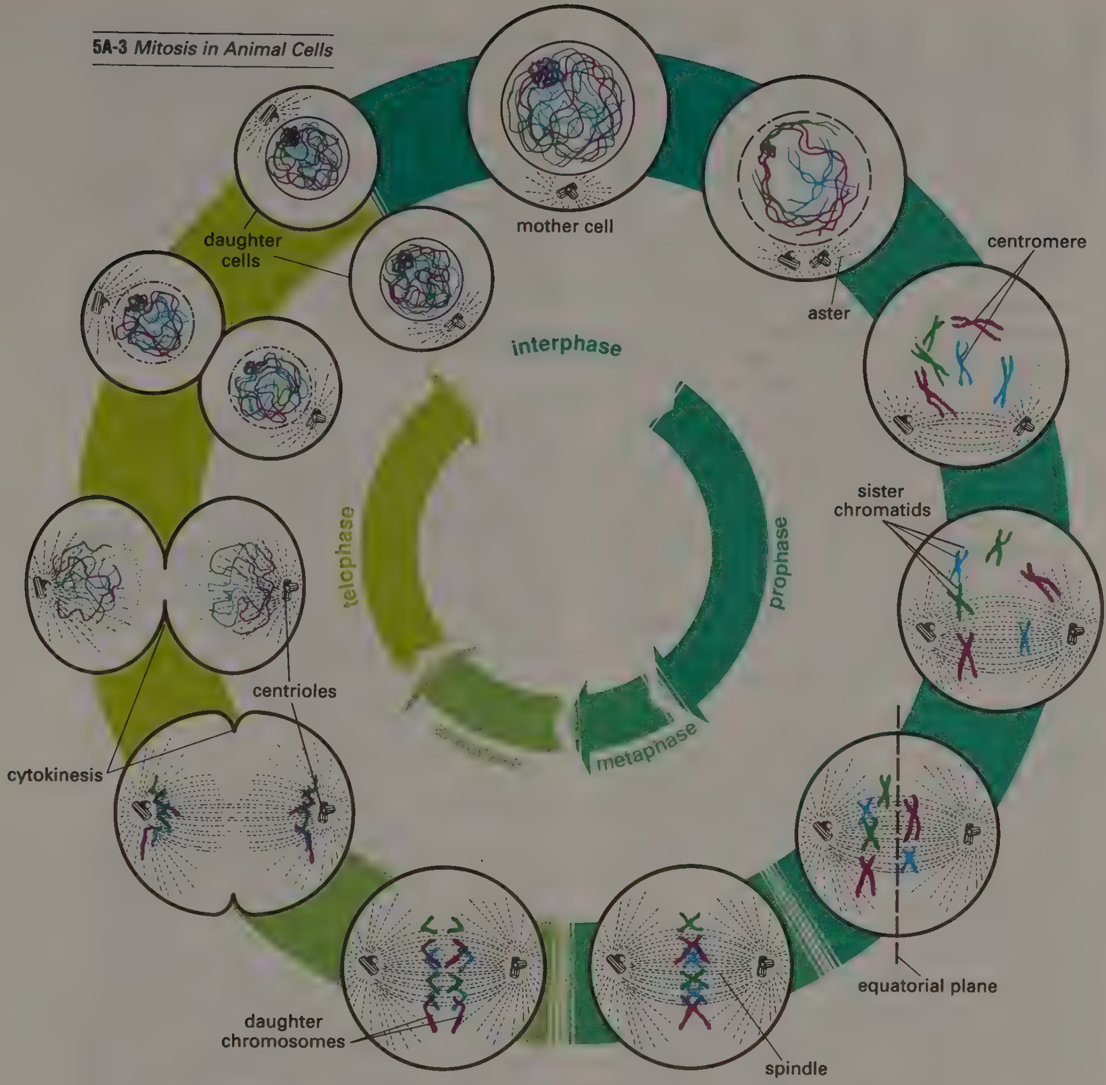
- ❑ Demonstrate an understanding that heredity and environment interact to determine an organism's physical make-up, but also understand that humans have a spiritual nature.
- ❑ List some human characteristics that are inherited and others that depend upon the environment.
- ❑ Describe and define a gene.
- ❑ Explain the nature of cell division, listing and describing the phases of mitosis.
- ❑ Describe the significance of mitosis in asexual reproduction and in the production of multicellular organisms.
- ❑ List and describe the major differences between mitosis and meiosis.
- ❑ Describe the limited significance of meiosis in genetic variation.
- *❑ Describe cloning and discuss potential problems regarding the cloning of humans.

*From a Facet.

Answers–Review Questions 5A-1 *(p. 113)*

1. **(1)** Inherited genetic potential (species and individual characteristics); **(2)** environmental factors; **(3)** spiritual nature and condition
2. **(a)** Tail, four legs, body covered with fur, whiskers, smooth tongue; **(b)** length and shape of ears, particular coloring of fur, type of hair (short, long, straight, curly), length of body, type of nose (long, pug)
3. **(1)** Functions as individual unit; **(2)** reproduces (duplicates) itself accurately; **(3)** can be inherited; **(4)** composes nuclear material of cell; **(5)** fundamentally identical in kind and amount in

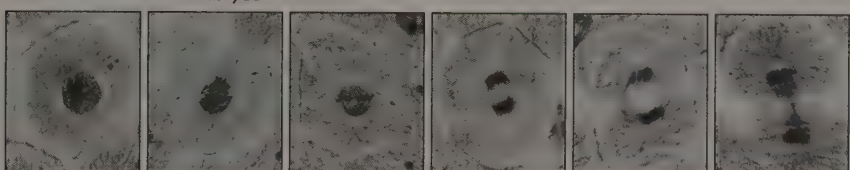
5A-3 *Mitosis in Animal Cells*



The phases of mitosis are a continuous process; the dividing lines between the phases are for convenience. Use the photos at the bottom of this page to reinforce this general idea. Using diagram 5A-3, carefully trace chromosome behavior; the daughter cells have the same genetic make-up as the mother cell because of DNA replication (pp. 66-68). Mitosis merely ensures that each daughter cell has a complete copy of the parent cell's genetic information. Quiz students over the significance of each step.

As the daughter chromosomes move along the spindle, they appear as a "V" with the apex toward the centriole.

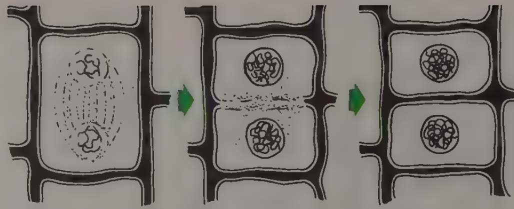
Mitosis in Whitefish Embryos



each cell of an organism; **(6)** fundamentally identical within species; **(7)** responsible for biosynthesis

diploid: diplo- (two) + -oid (form or shape)

Visual 5A-2 can be used to teach mitosis. Use colored pens to highlight the various chromosome pairs. Place this visual under a clear transparency so that the original transparency will not be damaged. Have students note the diagram in their text rather than copying it.



5A-4 *Cytokinesis in plants:* (left) *the end of mitosis,* (center) *the formation of a division plate,* (right) *daughter cells*

the middle of the cell and grows outward until it separates the two daughter cells. Another difference between plant and animal cell mitosis is that plant cells usually lack centrioles.

In some unicellular organisms all the phases of mitosis happen within the nuclear membrane. When mitosis is complete, the nuclear membrane invaginates to form two nuclei.

The length of time necessary for mitosis differs for various types of cells. Some procaryotic cells are able to complete a cell division in about 10 min. and are ready to divide again after an additional 10 min. of growth. Most plant cells require about 30 min. for mitosis. Some animal cells require about 3 hr. to pass from interphase to daughter cells.

Interphase may be extremely short for some cells. Embryos, for example, must form many cells rapidly. Almost as soon as the nuclei in the daughter cells have formed, the two nuclei may begin another prophase, even before cytokinesis is complete. Later these cells will grow and specialize.

Most cells in the body will divide to replace damaged or dead cells. Skin cells, for example, divide constantly to replace the skin we rub and wash off. Bone cells can divide, although much more slowly than skin cells, and grow to repair broken bones. Some cells, once they have reached maturity, will never carry on mitosis again. Nerve cells in the human brain, for example, may grow in size and replace worn out or damaged cell parts, but they will not divide. When brain cells die, they cannot be replaced.

Note that some organisms have the same number of chromosomes. White pines, Irish potatoes, and watermelons all have 24 chromosomes. They are, however, different chromosomes with different genes.

Students must understand chromosome numbers in order to comprehend meiosis and genetics. Progress slowly. Use the colored chromosomes in diagram 5A-3 to illustrate homologous pairs.

Chromosome numbers

The number of chromosomes within an organism's cells is one of its species characteristics. If evolution were true, it would be logical to assume that the smaller species with the least complex structures would have smaller and fewer chromosomes. But this is not the case, as you can see in Table 5A-5.

Look at figure 5A-6. A human cell was stopped during mitosis by dissolving the spindle, and then the cell was stained to reveal chromosomes and squashed so that the chromosomes were separated. It was photographed and the picture was cut, and the chromosomes were arranged into groups according to their length and centromere location. The result is called a **karyotype** (KEHR ee uh TYPE).

Looking closely at the karyotype in figure 5A-6, you will see that chromosomes occur in pairs. There are 2 number one chromosomes, 2 number two chromosomes, and so forth. Humans actually have 23 pairs of chromosomes. These pairs are called **homologous** (hoh MAHL uh gus) **pairs of chromosomes.** Each member of a *homologous pair of chromosomes* is called a **homologue** (HAHM uh LAWG). In a karyotype homologues are arranged in *homologous pairs.*

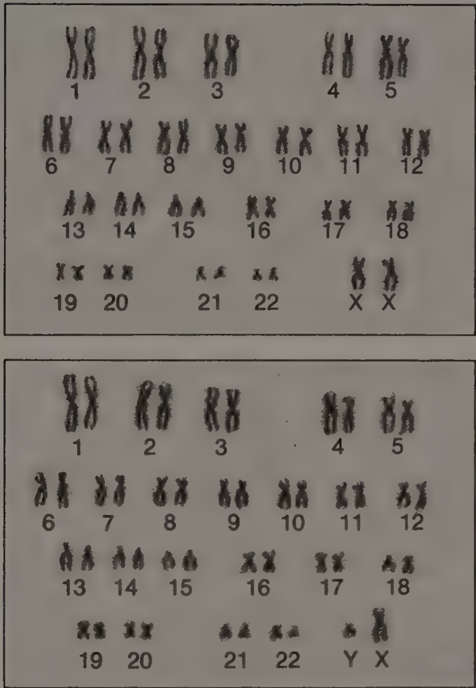
When a cell has homologous pairs of chromosomes, it is said to be **diploid*** (DIP LOYD) (abbreviated *2n*). Most common organisms are diploid. The diploid number of an organism is its

5A-5 Diploid Chromosome Numbers in Some Organisms

Name	Number (2n)	Name	Number (2n)
Plants		**Animals**	
pea	14	fruit fly	8
red clover	14	housefly	12
onion	16	honeybee	32
cabbage	18	cat	38
corn	20	mouse	40
watermelon	22	rat	42
lily	24	Rhesus monkey	42
tomato	24	rabbit	44
white pine	24	cattle	60
cotton	26	donkey	62
African violet	28	horse	64
white clover	32	crayfish	200

Answers–Review Questions 5A-2

1. A chromosome is a protein-coated DNA strand; its proteins may help in replication of DNA and transcription of RNA. A chromatid is a DNA duplicate, one-half of a chromosome. Chromatids are attached by the centromere during mitosis.
2. (See 5A-3.) **(1)** Interphase is the period between cellular division, not actually a phase of mitosis. The cell carries on normal metabolism; the double centriole is just outside the nucleus. Inside the nucleus, chromatin is producing RNA. Toward the end of interphase, all chromosomes are replicated, and sister



5A-6 *Human karyotypes: female (above) and male (below)*

number of chromosomes. The human diploid number is 46 (2n = 46).

Both homologues in a pair have genes for the same characteristics. In other words, humans have 2 of almost every gene, 1 on each homologue of the pair. Assume, for instance, that humans have a gene for tongue length on chromosome number one.* Since humans have a homologous pair of chromosome number one, everyone has 2 genes for tongue length. We will discuss later the significance of having pairs of genes.

Uses of mitosis

Mitosis results in two cells that have the same DNA. In other words, they both contain the same genetic information. The most obvious uses of mitosis are growth, repair, and replacement of cells in multicellular organisms. For example, your 10 trillion cells are the result of repeated mitosis of your original cell. Also, injured parts of your body are repaired by the growth of new cells to replace the damaged ones. Often cells are needed to replace those that wear out naturally.

Many organisms are able to carry on reproduction by undergoing mitosis. Any form of reproduction which involves only mitotic cell divisions is called **asexual reproduction.** For example, if a unicellular organism goes through mitosis, the organism has reproduced asexually.

Many colonial organisms are able to reproduce asexually by *fragmentation.* Breaking a simple colony in two and then permitting additional mitosis to replace missing cells will result in asexual reproduction. Many algae, fungi, and bacteria reproduce asexually by fragmentation.

Some multicellular organisms can, by producing a large number of cells in a certain area, produce a new, small organism on the side of the parent. This is called *budding*. Some plants, like the strawberry, carry on a similar process and produce small plants on the ends of special stems or on other plant parts.

Many multicellular organisms are able to reproduce asexually by forming spores. A **spore*** is a cell (sometimes cells) with a hard protective covering. Often a species is kept alive because the organism forms spores that live in an inactive state through a dry, cold, or otherwise unfavorable period. Spores of some molds can remain alive for over 50 years. Many organisms such as mosses and fungi reproduce and are spread predominantly by spores.

*This is a hypothetical example; scientists are just now determining where genes are located on chromosomes.

spore: (L. SPORA, seed)

Be sure that students understand that cells still have homologous pairs of chromosomes after mitosis. Mitosis separates the sister chromatids, not the homologous pairs of chromosomes.

If evolution were true, the simplest organism ought to have the fewest chromosomes and man ought to have the most, but this is not true. Students should be expected to know only the chromosome number of man (and later the fruit fly). The others are presented only to show the significant variation in numbers.

Review Questions 5A-2

1. Describe a chromosome. Distinguish between a chromosome and a chromatid.
2. List in sequence the phases of mitosis and describe each.
3. What is the difference between mitosis and cytokinesis?
4. What is the normal human diploid chromosome number?
5. List several types of asexual reproduction and describe each.

chromatids are attached by a centromere. **(2)** Prophase is the first phase of mitosis. The centrioles divide and migrate to opposite sides of the nucleus. The spindle forms between the centrioles. Inside the nucleus, the chromosomes begin to coil and become shorter and thicker. The nuclear membrane disintegrates, and the nucleolus disappears. **(3)** In metaphase the sister chromatid pairs migrate to the center of the spindle. The centromeres are on the equatorial plane, and chromosomes have an "X" appearance. **(4)** During anaphase the centromeres appear to pull the daughter chromosomes along the spindle fibers toward opposite poles. They appear to have a "V" shape. **(5)** In telophase, at each centriole, a new nucleus begins to form, daughter chromosomes begin to uncoil, nucleoli reappear, and nuclear membranes reform. The spindle disappears, the plasma membrane constricts at the center of the cell in human and animal cells, and the cytoplasm divides (cytokinesis).

3. Mitosis involves reproduction by duplication and division of the nuclear material of a cell. Cytokinesis is the division of the cytoplasm which usually follows mitosis.
4. 46 (23 pairs)
5. Mitosis of unicellular organisms results in asexual reproduction. Fragmentation of colonial organisms occurs when the colony is broken to form 2 individuals. Some organisms reproduce asexually by budding–the growing of a new individual on the parent. Some organisms are able to produce spores (a cell or cells enclosed in a protective case) through mitosis and can thus reproduce asexually.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. The Facet presents a definition of *clone,* the economic advantage of plant clones, the biological possibility and difficulty of animal clones, and the spiritual significance of human clones.

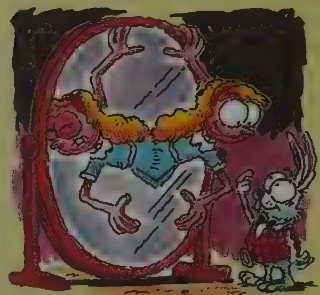
The term **clone** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Other suggested terms for students to learn include *natural clone, artificial clone, identical twins,* and *fraternal twins.* The terms *runner* and *rhizome* are also studied in Chapter 13.

Man helps many natural plant clones if it is economically profitable to him. In such cases the division between natural and artificial clones may become blurry. If man forces the cloning, it is artificial, even if the plant can reproduce asexually by itself. If the plant does it by itself, the clone is natural.

FACETS OF BIOLOGY

5A-1



Clones and Cloning

If you speak of cloning, many people think of a scientist working on diabolical experiments to make exact duplicates of himself. People are relieved to learn that such activities are, at least at present, beyond the scope of scientific possibility. That does not mean that clones are rare. In fact, many clones are common in nature. Many manmade clones have existed for centuries. Even human clones exist and have been common for a long time.

A **clone** is a group of genetically identical individuals. If an organism reproduces using only mitosis, the result is a clone. For example, if a unicellular protozoan or alga goes through mitosis and forms 2 cells, both of those cells are members of a clone. As they grow and divide repeatedly, the clone gets larger.

Natural clones

Asexual reproduction that an organism carries on by itself produces *natural clones;* thus, unicellular organisms form clones as they reproduce. Any multicellular organism that reproduces by fragmentation, budding, or asexually produced spores also forms natural clones. Some organisms in the animal kingdom, like jellyfish, some worms, and some insects, reproduce asexually and thus produce natural clones. Most of the more familiar animals, like fish, birds, and mammals, normally reproduce sexually and thus do not form natural clones.

In the plant kingdom natural clones are more common and are even commercially beneficial. If a strawberry grower found a strawberry plant which grew well in his climate and had the qualities of taste, texture, and color he wanted, he would clone the plant. Strawberries naturally reproduce asexually by *runners* (thin stems which grow tiny plants on their ends). In time the farmer would be able to fill his field with clones of the desirable strawberry.

Cattail seeds may carry the species to a new pond, but once established, asexual reproduction forms a new clump of plants. These plants grow from an underground stem called a *rhizome* making them natural clones. Tulips, irises, onions, peonies, lilies, ferns, mints, and other plants easily reproduce asexually and often form large natural clones.

Artificial plant clones

Many economically important plants do not naturally reproduce asexually but can be either helped or forced to do so. For example, the "eyes" of desirable varieties of the Irish (or white) potato are used to produce clones of that kind of potato. In time there can be fields full of genetic duplicates of this potato. Since man cloned this organism and helps to keep the clone going, it is said to be an *artificial clone.*

Planting the seeds of a seedless banana does not get more seedless banana plants. Banana plants are grown by planting the cut up pieces of their large underground stems. The genetic change which caused a seedless banana has been kept alive by cloning. Today seed-filled bananas are unknown to most people.

A similar situation is true of seedless grapes. Grape vines are woody plants and can be *grafted.* A stem of a seedless grape can be grafted into the root system of another grape plant. The grafted-in branch has the genetic make-up that will determine the kind of fruit produced. Since the branch has genes for seedless fruit, the

The Word "Clone"

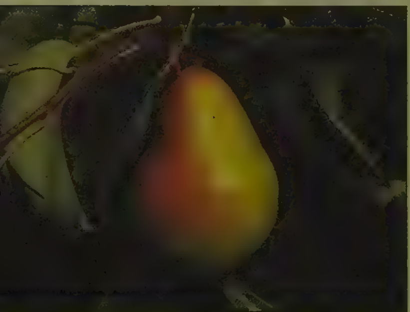
The word "clone" as a noun means a group of individuals produced asexually from a single parent or only one individual from such a group. The word "to clone" as a verbal means to produce clones.

Consider this riddle: The scientist cloned his prize clone. From the clone he took a choice clone and gave it to his identical twin saying, "This clone on my clone was cloned for you, clone."

An orchid bud is removed and sterilized. (a) A few cells from the bud are grown on sterile media. (b) Rotation encourages growth. (c) Eventually many small orchid plants can be placed in soil and grown to produce identical flowers.

plant is essentially a clone. Repetitions of this procedure result in a vineyard filled with a clone that produces seedless grape plants.

The grafting process is used to produce almost all named varieties of fruits and ornamental woody plants whether they produce seeds or not. Because of genetic recombinations happening each time the sexual reproduction necessary to produce a seed takes place, a seed from a Bartlett pear will not produce a Bartlett pear tree. The genetic traits that produce a Bartlett pear become scrambled as the seed is made. Bartlett pear trees are all members of a graft-sustained clone, as are all Granny Smith apples, Tiffany roses, and Georgia Bell peaches.



All Bartlett pear trees are members of a large clone. From the original tree the clones were produced by grafting.

Artificial animal clones

Artificial animal clones can be produced easily in only a few groups of organisms like sponges, jellyfish, corals, some worms, and insects. Often this type of cloning is done by forcing an organism to *regenerate* missing parts. A starfish, for example, can be cut into several pieces, each one of which can become a complete organism by regenerating its missing parts.

Starfish regenerating ray

Today the technology is available to clone some other animals. Frogs were used in some of the original successful experiments with cloning from the zygote stage. When the zygote became two cells, scientists separated the cells. Each cell then developed into a genetically identical individual–a 2-member clone. Scientists discovered that the zygote could also be separated at later stages into a larger number of individual cells and thus produce larger clones. There was a limit, however. The more cell divisions the zygote went through before the cells were separated, the less likely the cells were to develop into frogs. The size of the clone was thus limited.

Because frogs produce large ova, frogs were also used as experimental animals in another form of artificial animal cloning. Scientists are able to use ultra-fine needles to remove the nucleus from a frog's ovum, without destroying the cytoplasm's structure. They can then take a nucleus from a cell of another frog (originally cells from the intestine were used) and implant them into the ''empty ovum.'' This artificial zygote can develop into a frog. If several artificial zygotes are all prepared with nuclei from cells of the same frog, a clone of frogs can be developed. The number of individuals in such a clone is theoretically unlimited.

Visual 5A-3 can be used to outline the information contained in this Facet. Give examples and discuss techniques of cloning while presenting the various points of the transparency. Point out to students that they should know this material for testing purposes.

Sponges are cloned, grown, and then sold (see pp. 342-43). This is one of the few economic uses of cloning in the animal kingdom.

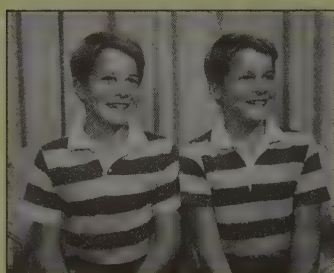
Fraternal Twins: More Than Just Minutes Apart

Fraternal twins are not members of a clone because they do not have the same genetic make-up. Fraternal twins are the result of two separate zygotes, both of which happened to be in the same womb at the same time. Fraternal twins may be brother and sister, or both of the same sex. If they are both of the same sex, they are no more alike than sisters or brothers who were born at separate times, except for their birthday.

The processes used to obtain clones of animals are expensive, and thus not profitable except for scientific experimentation where genetically identical individuals are essential. There are also limits to our current technology. At this time, needles and other devices needed for handling nuclei of small ova are not available. The cloning of mammals which have small ova (compared to those of a frog) is being worked on.

Human clones

Natural human clones exist: identical twins are naturally occurring clones of only 2 individuals. Identical twins have the same genetic make-up because they are the result of 1 fertilized zygote dividing into 2 cells which then separate. Normally these cells remain together and develop into a single individual, but in the case of identical twins each of the 2 cells implants itself in a different place in



the womb (uterus) and develops into an individual. There are a few examples of identical triplets, and some rare examples of identical quadruplets. As with the dividing of the frog zygote, there appear to be limits as to how many individuals can be cloned by the division of a single zygote.

The artificial cloning of humans will be as difficult as cloning mammals, for the ova are similar in size. (The artifical implanting of a zygote into a womb for development has already been accomplished. See pages 162, 165.) Scientists predict that the technology needed to clone humans by using the implanting of nuclei into ova will be developed within your lifetime.

Although some Christians may disagree, many Christian scholars believe that each member of an artifical human clone would have a soul. Identical twins are natural clones, and they do not share one soul. Although they are genetically identical, they sin independently, and they must be saved individually. Using this logic, it appears that if man develops enough technology to produce a human clone, each would still have an individual human soul in need of salvation just like everyone else.

But who should be cloned, and for what purpose? Cloning people who are very intelligent, talented, athletic, healthy, or who have other outstanding characteristics seems desirable at first glance. Most Christians would object to such cloning because it presents too many potential spiritual problems. For example: such a costly procedure would probably have to be done by government(s), especially those in countries with undesirable or declining populations. Also a shortage of certain "types" of people may make cloning desirable. It is not impossible to imagine governments selectively cloning strong, docile people with low intelligence to serve as a work force. (Governments have done worse things with human life in the past!)

If the state pays for the cloning, who "owns" the child? Most governments will not want a child that they "paid for" brought up in the "nuture and admonition of the Lord" (Eph. 6:4). In fact, having the cloned individual even aware of any form of "religion" may make him less able to serve the government as desired.

The Bible teaches us that "children are an heritage of the Lord" (Ps. 127:3) given to the parents to raise according to God's precepts. Christians need to stand against the improper use of scientific knowledge and the government's assumption of rights it does not have. (Additional Biblical principles regarding this and similar considerations are discussed on pages 160-67 and 638-43.)

Review questions on page 124.

Some multiple births involve a pair of identical twins and one or more fraternal individuals. Siamese twins (those born attached at some point or sharing some structure) are generally identical twins whose original zygote did not completely separate before it was implanted in the womb.

The negative picture of human genetic manipulation presented here is intentionally one-sided. Arguments for the other side, as well as a more thorough presentation of the entire topic, are presented in the next chapter. Chapter 24 also contains related material.

Meiosis

Simple mathematics tells you that if a father's **sperm*** contained 23 pairs of chromosomes (46), and a mother's **ovum*** (OH vum) (pl., ova) contained 23 pairs of chromosomes (46), the number of chromosomes in their baby's cells would be 46 pairs (92). Normal human cells, however, have only 23 pairs of chromosomes. As the parents' sperm and ovum were forming, the chromosome number of each was reduced to the **haploid*** (HAP LOYD) number (abbreviated n). A haploid cell is one that has only one chromosome from every pair. In humans the haploid number is 23 (n = 23). When the two haploid gametes (n) from the parents united, a diploid cell called a **zygote*** (n + n = 2n) was formed. After countless mitotic divisions, their baby entered the world.

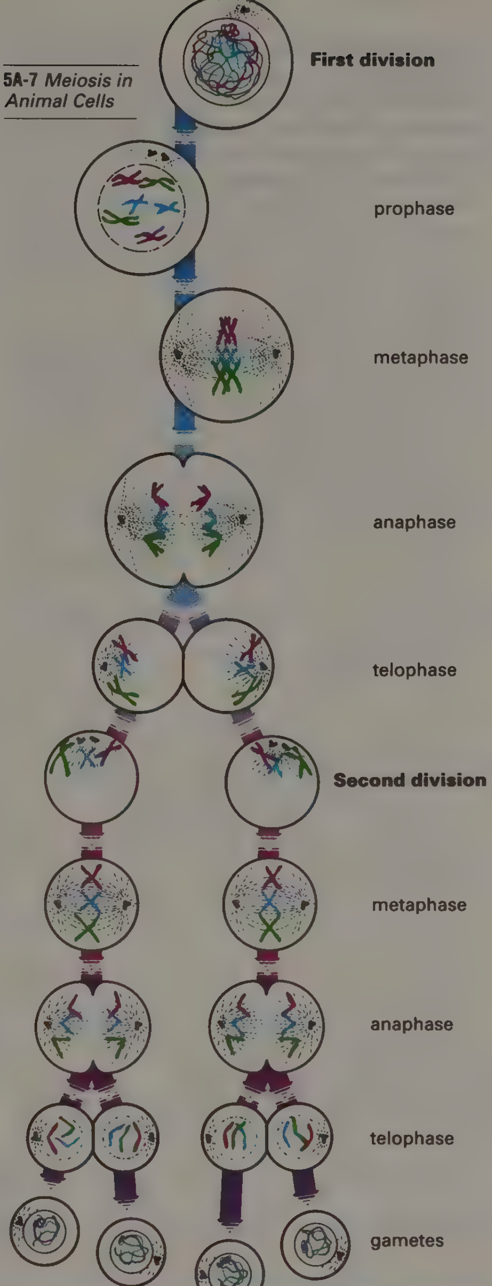
Think about the cell division necessary to form a haploid cell. It cannot be a random dividing of chromosomes. A haploid cell must have 1 of every homologous chromosome pair. Under normal circumstances a gamete does not have 2 of one pair of chromosomes and none of another pair. If it did, the zygote it formed might not be diploid even though it had the right number of chromosomes. It might have none, 1, 3, or 4 of a homologue rather than a pair. If a zygote does not have all its chromosomes in pairs, it may lack genes that are on the chromosomes for which it has only one homologue. Or it may have too many of the genes that are on the chromosomes for which it has 3 or 4 homologues. Either case can be harmful.

To form a haploid cell (gamete), **meiosis** (mye OH sis) must occur. Meiosis is the reduction of a cell's chromosome number from diploid to haploid by two consecutive cell divisions.

The first division of meiosis

❑ *Prophase and metaphase* The prophase and metaphase of the first division of meiosis is similar to that of mitosis with one major difference. For metaphase not only the sister chromatids but also the *homologous pairs of chromosomes* line up together on the equatorial plane. Since both of the chromosomes in the homologous pair have replicated, there are 2 pairs of sister chromatids together. The 4 chromatids are called a *tetrad.*

5A-7 *Meiosis in Animal Cells*



sperm: sperm-, sperma-, or spermato- (Gk. SPERMA, seed)

ovum: (L. OVUM, egg)

haploid: hapl- (Gk. HAPLOUS, single) + -oid (form or shape)

zygote: (Gk. ZUGOUN, to yoke)

This diagram uses the same cell that was used on page 115. Use the similar chromosome number and colors to compare meiosis and mitosis.

A discussion of meiosis can begin with the mathematical impossibility that would result if the egg and sperm contained the diploid number of chromosomes. Cain and Abel would have had 92 chromosomes. Adam and Eve's grandchildren would have had 184. Their children would have had 368. The fourth generation would have had 736 and so on.

If students understand that chromosomes occur in pairs, the idea of each parent's contributing one member of a pair should make sense to them. Meiosis makes a single cell which contains one of each pair of chromosomes.

Visual 5A-4 can be used to teach meiosis. Use colored pens to highlight the various chromosome pairs. Place this visual under a clear transparency so that the original will not be damaged. Have students note the diagram in their text rather than copy the visual.

Note that after the first division of meiosis, the cells are haploid. The second division separates the sister chromatids, forming 4 haploid cells, some of which degenerate in some forms of meiosis (see oogenesis, pp. 121-23).

gamete: (Gk. GAMETE, spouse)

isogamete: iso- (same or equal) + -gamete (spouse)

heterogamete: hetero- (other) + -gamete (spouse)

spermatogenesis: spermato- (seed) + -genesis (beginning)

Visual 5A-5 can be used to review and compare mitosis and meiosis. Ask questions to help students arrive at the material on the visual. Additional comparisons are possible.

❑ *Anaphase* Rather than the sister chromatids separating as in mitosis, the homologous pairs separate, and the sister chromatids of each pair remain together. The homologues then travel to the ends of the spindle.
❑ *Telophase* The telophase of the first division of meiosis is the same as in mitosis, except that the chromosomes usually do not uncoil. The 2 new cells enter directly into the second division of meiosis.

The second division of meiosis

❑ *Prophase and metaphase* Usually the spindles in the 2 cells form in the opposite direction from the spindle in the original cell. The chromosomes (composed of a set of sister chromatids) line up on the equatorial planes.
❑ *Anaphase* The sister chromatids separate, and the resulting daughter chromosomes travel on the spindle fibers toward opposite poles.
❑ *Telophase* The 4 haploid cells reform their nuclei.

Gametes

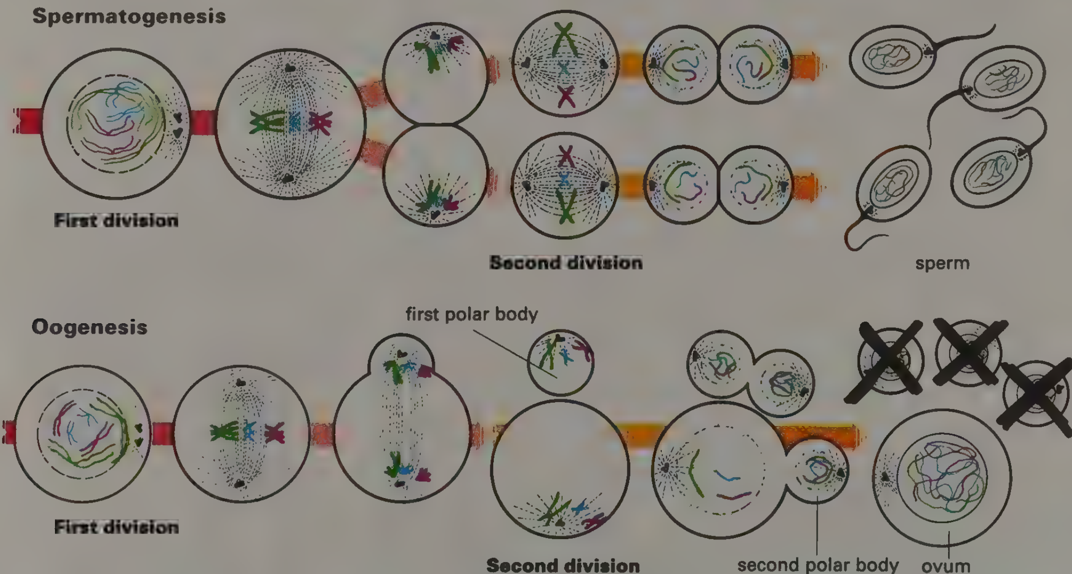
Gametes* are those haploid cells which, when they unite, form a diploid cell called a zygote, the first cell of a new individual. The process of forming a zygote–the union of gametes–is called **fertilization.**

Some organisms produce gametes which are all alike, called **isogametes*** (EYE soh guh MEETS). Usually isogametes move by cilia or flagella. Fertilization occurs when 2 isogametes unite. Many algae and fungi produce isogametes.

Humans, all animals, many plants, and a few other organisms produce **heterogametes*** (HET uh roh gah MEETS). A heterogamete is usually either a sperm formed by a male, or an ovum formed by a female. Sperm are usually smaller than ova and can move. The ovum, if it moves, must be moved by structures around it. (An ovum is sometimes called an egg. The term *egg*, however, properly applies to the ovum with accessory structures–like a shell–such as a bird egg.)

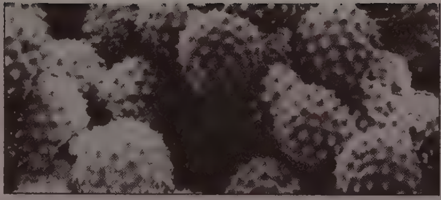
The forming of sperm is called **spermatogenesis*** (spur MAT uh JEN ih sis). Notice that in

5A-8 *A comparison of spermatogenesis (top) and oogenesis (bottom)*



Answers–Review Questions 5A-3 *(p. 124)*

1. Sister chromatids are DNA-duplicate strands joined by a centromere; 2 sister chromatids constitute a chromosome. A homologous pair of chromosomes is one of the chromosome pairs in the cell. Human cells have 23 homologous pairs; both homologues in a pair have genes for the same characteristics.
2. **(a)** Somatic cells (cells of most human organs or tissues); **(b)** Gametes (sperm or ova)
3. **(a)** First division–In prophase and metaphase, homologous pairs line up on the equatorial plane, forming 2 pairs of sis-



Plant Meiosis

Although the meiosis of most plants is similar to the forming of sperm and ovum, their cytokinesis is quite different. A *pollen grain* contains all the male haploid nuclei from the meiotic divisions of a single cell. Pollen also retains a great deal of cytoplasm: enough stored food, in fact, that many insects sustain their lives by eating pollen. Only one of the haploid nuclei *(the sperm nucleus)* will actually form the zygote.

The ovum of a plant contains several haploid nuclei because cytokinesis does not usually occur until after the *ovum nucleus* has been fertilized by the sperm nucleus, forming the zygote. The other haploid nuclei of the ovum either disintegrate or fuse, some with themselves and others with nuclei from the pollen grain to form structures of the seed. The fertilized ovum of most plants develops into a tiny plant inside the seed.

spermatogenesis, 4 functional gametes are formed. If you follow the chromosomes, you will notice that actually there are 2 pairs of identical sperm. In human sperm, as in sperm of other species, the cells formed by meiosis lose most of their cytoplasm and form a flagellum. The compressed DNA in the nucleus of the sperm is then moved toward the ovum by the flagellum.

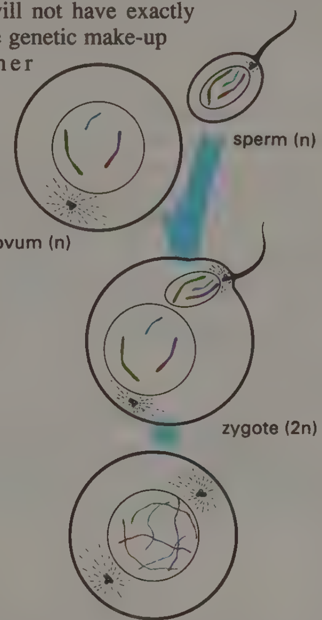
The forming of an ovum is called **oogenesis*** (OH uh JEN uh sis). During the cytokinesis of the first meiotic division, 1 of the 2 cells receives most of the cytoplasm. The cell that receives the small amount of cytoplasm is called the *first polar body*. When the large cell divides the second time, again 1 of the 2 cells gets the majority of the cytoplasm and forms the ovum. The cell which gets very little cytoplasm is the *second polar body*. The first polar body often goes through the second meiotic division, forming 2 polar bodies. Oogenesis therefore results in 1 ovum and 3 polar bodies.

In humans and animals the polar bodies soon disintegrate. The large quantity of cytoplasm in the ovum is necessary for the development of the zygote. The stored food and the cellular structures of the ovum's cytoplasm will be used during the period of rapid cell division at the beginning of the embryo's life.

Sexual reproduction

The union of haploid gametes, resulting in a diploid zygote, is **sexual reproduction.** It results in offspring which are not genetically identical to either parent. In sexual reproduction one of every homologous pair of chromosomes comes from one parent, and the other homologue comes from the other parent. The offspring, therefore, have one chromosome of every pair from each parent.

Inevitably one parent does not have exactly the same genes for a particular characteristic as the other parent has. Since each organism receives one gene of each set from each parent, the offspring will not have exactly the same genetic make-up as either parent.



5A-9 *In sexual reproduction two haploid cells unite to form a zygote.*

oogenesis: oo- (Gk. OION, egg) + -genesis (beginning)

The sexual reproduction of plants is a difficult concept, not necessarily significant for all students. This box may be omitted, or this material may be covered with the section on plants (see box on related material, p. 332).

ter chromatids (tetrad). In anaphase, homologous pairs separate, but the sister chromatids of each pair remain together. In telophase, the cell divides; each resulting cell contains the haploid number of chromosomes. **(b)** Second division–In prophase and metaphase, the chromosomes line up. In anaphase, the chromatids separate, and resulting daughter chromosomes travel to opposite poles. In telophase, the 4 haploid cells reform their nuclei.

4. **(1)** Spermatogenesis (formation of sperm); **(2)** oogenesis (formation of ovum)

Answers—Facet 5A-1

*1. The noun *clone* refers to a group of genetically identical organisms (or one of a group of genetically identical organisms). The verb *to clone* refers to the act or process of reproducing organisms asexually, thus making a clone (noun).
2. Natural clones are formed by organisms that reproduce asexually without human help. Artificial clones are formed when organisms are forced to reproduce asexually by human intervention.
3. When a desirable set of genetic traits occurs in certain plants, scientists are able to clone them, thus keeping the desirable characteristics alive and obtaining enough plants of that type to produce harvestable quantities. Seedless bananas, Bartlett pears, Tiffany roses, and many other named varieties of plants not commercially grown from seed are cloned.
4. Inducing the division of the zygote can clone some organisms. The number of individuals that result from such techniques is limited. Removal of an ovum's nucleus and the substitution of another nucleus has been successful in certain large-ovum species.

Biological Terms

species characteristic
individual characteristic

The Mechanism of Heredity

genetics
gene
chromosome

Mitosis

mitosis
interphase
centromere
sister chromatid
mother cell
prophase
aster
spindle
metaphase
anaphase
daughter chromosomes
telophase
cytokinesis
daughter cells
karyotype
homologous pair of chromosomes
homologue
diploid
asexual reproduction
spore

Meiosis

sperm
ovum (pl., ova)
haploid
zygote
meiosis
gamete
fertilization
isogamete
heterogamete
spermatogenesis
oogenesis
sexual reproduction

Facet

clone

Answers begin on page 122.

Review Questions 5A-3

1. Distinguish between a set of sister chromatids and a homologous pair of chromosomes.
2. List (a) several human cells that would contain the diploid chromosome number and (b) the human cells that would contain the haploid chromosome number.
3. What happens to the chromosomes during (a) the first division of meiosis and (b) the second division of meiosis?
4. Name the two types of meiosis that are carried on by humans.

Facet 5A-1: Clones and Cloning, pages 118-20

1. What is meant by the term *clone* (noun) and *to clone* (verbal)?
2. What is the difference between natural clones and artificial clones?
3. In what way is cloning economically advantageous in the plant kingdom? Give several examples of plants that are cloned commercially.
4. Describe the two methods used to clone larger animals (like amphibians, fish, birds, and mammals).
5. What is the difference between identical twins and fraternal twins? Which are clones? Explain.
6. List several Biblical principles (teachings) that may be violated by human cloning.

Thought Questions

1. What are the advantages and disadvantages of asexually reproducing apple trees as opposed to sexually reproducing them?
2. What advantages would a clone of an organism (like a fruit tree) have for a farmer?
3. What would be the advantages and disadvantages of cloning humans?

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*5. Fraternal twins develop from 2 separate ova and 2 separate sperm. They are not genetically identical and thus are not clones. Identical twins develop from a single ovum and a single sperm. They are thus genetically identical and are clones.

6. That children are a ''heritage of the Lord,'' given to parents to be raised according to Christian principles, could easily be ignored when and if humans are cloned. The government's authority over human life could easily be abused if the government begins to see humans as something it owns.

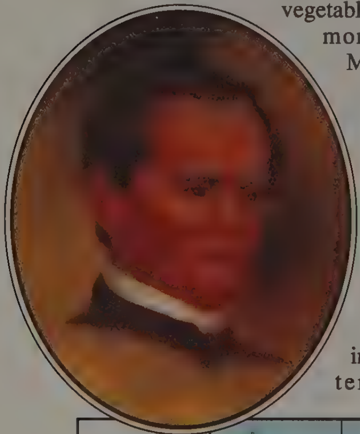
*From a box.

Answers–Thought Questions

1. Reproducing apple trees asexually produces trees identical to the parent tree, which is an advantage if all the characteristics of the fruit are desirable, but a disadvantage if some variation is desired. Sexual reproduction produces trees with slightly different fruit.
2. It would allow him to produce more organisms identical to the parent.
3. The advantages of cloning humans lie in the ability to select the characteristics that will be reproduced. With cloning, a person with desirable genetic characteristics could be reproduced exactly with no variations. Genetic defects could be avoided. The disadvantages, besides the obvious question of whether it would be rebellion against God's plan and design, are varied. Cloning would raise ethical questions concerning parentage, individuality, and ''personhood.'' Society depends on the contributions of individuals for variety and growth; this variety and growth could be substantially curtailed. The cloning process itself could be very uncertain. Technical problems could cause unpredictable, dangerous results. The full scope of issues that cloning raises is not yet known.

5B–Basic Genetics

Gregor Mendel was born in 1822 on a farm in Heinzendorf, Austria. At age 21 he entered the Augustinian order of the Roman Catholic church. As a monk he studied science at the University of Vienna and became an excellent mathematician. Later, as a schoolteacher, he engaged in many scientific activities. He recorded sun spots, read Darwin (with whom he disagreed), and maintained 50 beehives in which he tried to mate various European, American, and Egyptian types of bees. In 1857 Mendel began a program of selective breeding of peas in a small plot in the vegetable garden of Konigster monastery near Brunn, Moravia.



Mendel's experience in breeding and raising plants and animals on his father's farm, along with his mathematical and experimental science background from the university, equipped him well to investigate heredity. After 8 years of raising thousands of pea plants and recording and classifying many pages of notes, Mendel wrote a paper which presented a set of conclusions now called **Mendelian genetics.** In 1868 Mendel became the abbot of the monastery, and political problems forced him to give up most of his scientific work. In 1884 he died of a kidney disorder.

Gregor Mendel's paper on heredity in peas was published in 1865 but lay unnoticed in libraries for about 35 years. In 1900, after scientists had learned much about the cell, they rediscovered the paper and recognized its worth. Mendel became known as "the Father of Genetics." To understand modern genetic theories, you must understand what Mendel discovered about heredity.

Mendelian Genetics

Mendel ordered 34 varieties of pea seeds, planted them, and observed their characteristics. From those varieties he chose 7 *sets of opposing characteristics*. For example, he noted that peas are either about 6 ft. tall or about 2 ft. tall. Tall and short are a set of opposing characteristics. Pod color is either green or yellow, another set of opposing characteristics. Peas are round or wrinkled.

5B-1 *Gregor Mendel (left) and a summary of the sets of characteristics he observed in peas (below).*

Mendel was actually a substitute teacher. Although he took the exam required of full-time teachers before *and* after he graduated from college, he failed both times.

He refused to have the monastery pay a tax on religious institutions, a tax which he believed to be unfair. He spent a great deal of his time fighting legal battles.

Mendel's work was done about 140 years ago, but even now much of what is known about genetics is based on and illustrated by his work. Today Mendel's work is studied because of its historical value and because it clearly illustrates the principles basic to an understanding of currently accepted genetic principles.

dominant trait	tall plants	axial flowers	green pods	inflated pods	yellow peas	round peas	colored seed coat
X	X	X	X	X	X	X	X
recessive trait	short plants	terminal flowers	yellow pods	constricted pods	green peas	wrinkled peas	white seed coat
F_1 generation	all tall plants	all axial flowers	all green pods	all inflated pods	all yellow peas	all round peas	all colored seed coat
F_2 generation	787 tall: 277 short (2.84:1)	651 axial: 207 terminal (3.14:1)	428 green: 152 yellow (2.82:1)	882 inflated: 229 constricted (2.95:1)	6022 yellow: 2001 green (3.01:1)	5474 round: 1850 wrinkled (2.96:1)	705 colored: 224 white (3.15:1)

5B–Basic Genetics

Notes–Chapter 5B

The mastery-teaching techniques used in Chapter 5A continue in 5B. Mastery teaching is the only way to deal with the topics covered here. The warnings of Chapter 5A also continue; do not become so wrapped up in working crosses and arriving at correct ratios that both teacher and students miss the bigger picture. The goal is not that five years from now students be able to work out a pedigree for free and attached ear lobes, but rather that they have a practical understanding of genetics. The best way to achieve this goal is to work a few problems, answer a few questions, and apply a few principles to problems at this level. If the students are given information only, they usually do not really understand. The teacher must organize the instruction so that mastering genetic problem solving does not become a burden to the students.

The purpose of presenting variations of Mendelian genetics is not for student mastery, but rather for student appreciation. Students should recognize how complicated the prediction of genetic traits among offspring is. Simple observation of any large family will show that basic Mendelian concepts either do not work or are not the only thing at work in inheriting characteristics. The basic principles do work, but there is *more* at work than the basic genetic trait. (Who cares if you can't taste PTC or if your ear lobes are attached?)

Because human genetic disorders are often the result of action of a single gene, they tend to adhere to the basic Mendelian rules better than do other traits (e.g., height, hair color, intelligence, or skin tone). Thus human genetic disorders have been used as examples when possible. The disorders are what cause people to be concerned about inheritance of traits.

In the next chapter genetic screening and engineering will be significant topics.

filial: (L. FILIUS, son)

Most plants are designed to cross-pollinate. The gametes from one flower are carried to another by wind, water, or insects. Since the keel (lower petal) of pea flowers keeps the gamete-producing parts of the plant enclosed, they normally do not cross-pollinate.

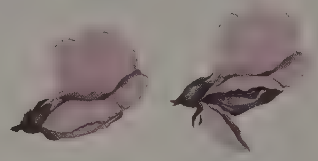
The concept of dominant and recessive is difficult for some students. Stress that the dominant gene completely masks the presence of the recessive gene. Use Mendel's pea plants as an example. This is not always true in other traits such as human height and hair color.

In the text, capital letters are used for dominant traits and lower-case for recessive. This method is not always used in genetics, but using it consistently in class helps avoid confusion.

Carefully go over illustration 5B-3. Present the concept with several repetitions, using different characteristics from illustration 5B-1.

Make sure the students realize that the traits that Mendel worked with are caused by genes. Review briefly the function of genes (p. 113) in gamete formation (pp. 121-22) and fertilization (p. 123). Mendel did not have this information while he was working out his concepts. It is actually somewhat surprising that he was able to develop them.

The flower of the pea plant made it ideal for genetic experimentation. The petals are arranged so that the pollen (which contains the male gamete) naturally fertilizes the pistil (which contains the female gamete) of the same flower. This is called **self-pollination.** If Mendel wanted to **cross-pollinate** it, he had to tear open the petals and remove the pollen sacs before they matured. When the pistil was to be fertilized, he could supply pollen from another pea flower.



5B-2 *The pea flower:* (left) *closed, resulting in self-pollination;* (right) *opened, ready to be cross-fertilized*

Mendel began his experiments with peas that had been self-pollinating and breeding *true:* in other words, the tall plants always produced tall plants, the short plants always produced short plants, and so forth. He called these the parent plants and used the symbol P_1 to represent them. One of Mendel's experiments involved cross-pollinating a tall pea plant with a short pea plant. He called the offspring of this cross the **first filial* generation** (F_1). All the F_1 plants were tall. He allowed F_1 plants to self-pollinate and produce the **second filial generation** (F_2). Of the 1,064 plants in Mendel's F_2 generation, 787 of them were tall, and 277 of them were short.

Mendel's concepts

To explain the outcome of this experiment and similar results he obtained when he crossed peas with other sets of opposing characteristics, Mendel proposed several concepts. His concepts have been validated as scientists have observed similar results in other organisms and the cellular structures responsible for heredity. The following concepts are illustrated in the crosses described in figure 5B-3.

❑ **The concept of unit characteristics** Mendel stated that an organism's characteristics are caused by units which he called *factors* (now called *genes*), which occur in pairs. In pea plants the tall parent has two genes for being tall, which are represented by *TT;* and the short parent has two genes for being short, *tt*. Remember that genes (made of DNA) are responsible for inherited characteristics, that genes are located on chromosomes, and that most organisms have homologous pairs of chromosomes. Thus most normal organisms have *pairs* of genes in their cells.

❑ **The concept of dominant and recessive** Since the short plant of the P_1 could give only a short gene *(t)*, and the tall plant only a tall gene *(T)*, the F_1 generation was *Tt*. But rather than being medium-sized as expected, all the F_1 generation were tall. Mendel called a trait that expressed itself when factors for two opposing traits are present the **dominant trait** (caused by a *dominant gene*). The trait that is masked (hidden) when two genes for opposing traits are present is the **recessive trait** (caused by a *recessive gene)*.

❑ **The concept of segregation** Mendel reasoned that when a cell forms gametes, the genes separate (segregate) so that there is only one gene for each characteristic in each gamete. Our knowledge of the behavior of *chromosomes* in meiosis indicates that Mendel's description of gamete formation is accurate.

These concepts are also illustrated by the self-pollination which produced Mendel's F_2 generation of tall and short plants. Since the F_1 generation were all *Tt*, half of their pollen should contain a *T* gene and the other half a *t* gene. Half of the ova they produce should contain a *T* gene and the other half a *t* gene. This illustrates the concept of segregation.

The recessive gene *(t)* was not destroyed or altered when it was masked by the dominant gene in the F_1 generation; therefore, in the F_2 generation there are some short pea plants. Whenever both parent plants gave the recessive gene, the offspring expressed the recessive trait. This illustrates the concept of unit characteristics.

Notice the possible unions of the various gametes of the F_1 as illustrated in figure 5B-3. Three-fourths of the possible gamete combinations in the F_2 have at least one dominant gene; only 1/4 of them have two recessive genes. This, combined

Objectives–Chapter 5B

- ❑ Describe Mendel's work with peas and the relationship of his findings to observations of chromosomes during mitosis and meiosis.
- ❑ List and discuss Mendel's basic conclusions regarding inheritance.
- ❑ Demonstrate monohybrid (and dihybrid) crosses on Punnett squares and be able to interpret the results.
- ❑ Figure simple pedigree problems.
- ❑ Recognize and be able to explain modifications of Mendel's principles such as incomplete dominance, multiple gene interaction, and multiple alleles.
- ❑ Describe sex determination in humans.
- ❑ List and describe the inheritance of several human traits and genetic disorders.
- ❑ Demonstrate an ability to work simple problems dealing with sex-linked traits.

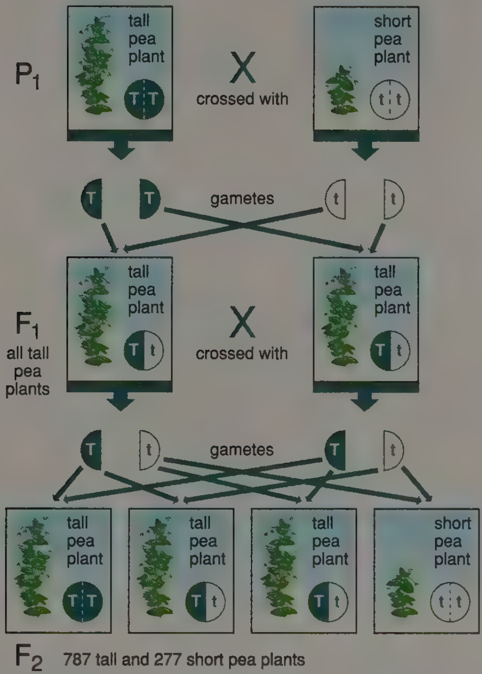
A basic understanding of Mendelian genetics is needed to appreciate the limits and capabilities of these areas.

Facets–Chapter 5B

The two Facets should be covered in general biology courses. The Facet on fruit flies can easily be covered in ten minutes. Since it is such a common laboratory example, students should be exposed to it.

The Facet about hemophilia presents a well-known, historical example of a principle being taught. A brief discussion of hemophilia, its causes and treatments, and the use of Laboratory Exercise 5B should be all that is necessary to cover this Facet.

with the fact that Mendel's F_2 generation results were 787 tall to 277 short (which is about 3/4 to 1/4), lends support to the concept of unit characteristics.



5B-3 *A summary of Mendel's crosses of tall and short pea plants.*

Genetic terms

Knowing the following genetic terms will help in our discussion of genetic principles:

❑ **Phenotype*** (FEE nuh TYPE) The expression of an organism's genes; what an organism is like (tall, green, constricted); not all genes result in a visible trait. For example, you inherited genes for digestive enzymes which are not seen but must work for you to be healthy. Expressing these genes is part of your phenotype.);

❑ **Genotype*** (JEN uh TYPE) The genes that the organism has (often expressed by letters such as *TT, Tt, tt,* and so forth);

❑ **Allele** (uh LEEL) One pair of genes which has equivalent positions on homologous (paired) chromosomes; these are often expressed by letters–for example, *T* or *t;*

❑ **Homozygous*** (HOH moh ZYE gus) The condition of both alleles in a cell (organism) being the same–for example, *TT* or *tt;*

❑ **Heterozygous*** (HET uhr oh ZYE gus) The condition of both alleles in a cell (organism) *not* being the same–for example, *Tt;*

❑ **Monohybrid*** (MAHN oh HYE brid) **Cross** A cross that deals with only 1 set of alleles–that is, with 1 set of opposing characteristics.

Suppose a man with the dominant phenotype (free earlobes) knows that he is homozygous for the trait. His genotype is *FF*. His wife has the recessive phenotype. What kind of earlobes does she have? The only genotype a person with the recessive phenotype can have is *ff*. (If she had a dominant allele, her phenotype would be different.) All the man's sperm contain the dominant allele *(F)*, and all the woman's ova the recessive allele *(f)*. All their children, therefore, would have the heterozygous genotype *(Ff)*. What would be the phenotype of these children?

5B-4 *Attached (top) and free (bottom) earlobes.*

Review Questions 5B-1

1. Who is "the Father of Genetics?" What did he do to earn this title?
2. Describe the (a) concept of unit characteristics, (b) the concept of segregation, and (c) the concept of dominance.
3. The gene for yellow peas is dominant over the gene for green peas. What is the difference between homozygous yellow peas and heterozygous yellow peas?
4. Compare and contrast the genotype and phenotype of an organism.
5. What is the difference between a gene and an allele?

phenotype: pheno- (to show) + -type (Gk. TUPOS, type)

genotype: geno- (beginning) + -type (type)

homozygous: homo- (Gk. HOMOIOS, same) + -zygous (to yoke)

heterozygous: hetero- (other) + -zygous (to yoke)

monohybrid: mono- (single) + -hybrid (L. HYBRIDA, offspring of different parents)

Some of the characteristics of a gene (discussed on p. 113) will now be more meaningful to the students. Consider reviewing those characteristics as you begin teaching this material.

Now that the students have mastered the basic concepts, it is wise to give the concepts names. If terms are introduced at the same time as concepts, the students often miss the concept in their confusion with the terms. This is a good place to use a straightforward, dictated definition for each term.

The half-circle gamete and the full-circle diploid individual illustrations will be used repeatedly in this section.

Note that although only one set of genes is indicated, there is actually one set in each cell of the pea plant. They are identical in all the cells of the plant because all of them are the result of mitosis.

Visual 5B-1 can be used here and with the next few pages, or it can be used as a review of the material. The definitions are not always identical to the ones in the glossary. This is designed to help oral presentation of the material. Students do not need to copy the definitions, because they are in the text and the glossary. This is designed for visual reinforcement of the concepts, not as a list of terms to copy and memorize.

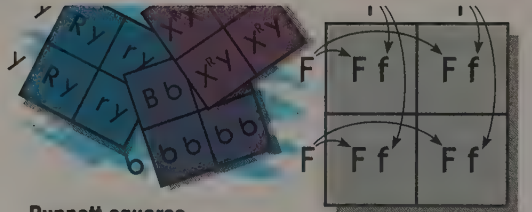
Answers–Review Questions 5B-1

1. Gregor Mendel did extensive experimental research on heredity, using garden peas for subjects, and published a paper of his results and conclusions.
2. **(a)** An organism's characteristics are caused by units (genes) which occur in pairs. **(b)** When a cell forms gametes, the genes separate so that there is only one gene per certain characteristic in each gamete. **(c)** When genes for two opposing traits are present, the recessive gene is "masked" by the dominant gene and its trait.
3. Externally (phenotypically) they are the same. Genotypically, however, they differ. Homozygous yellow peas are peas with two dominant genes *(YY)* for yellow characteristics. Heterozygous yellow peas have a dominant gene for yellow *(Y)* and a recessive gene for green *(y)* which is not expressed.
4. The genotype represents in symbols the genes found in an organism (e.g., *TT, tt, Tt*). A phenotype is the physical expression of an organism's genes (e.g., size, color, shape); not all genes are necessarily expressed.
5. *Allele* generally refers to one of a pair of genes that would normally be found in a diploid organism.

To increase class interest, use personal examples. Ask some students who have larger families or a number of relatives (especially grandparents) living nearby to survey their family's earlobes. Record the data on the board and use it to demonstrate the use of Punnett squares to show possible gamete combinations. This can be exceptionally helpful in teaching genetic ratios. If taking the survey is impossible or would take too much time, invent "hypothetical" families for students and even some "hypothetical marriages" among the students to teach these concepts.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet discusses why the fruit fly is such an ideal organism for genetic studies (when compared to other animals or humans) and what has been learned by fruit-fly study.

The terms **fruit fly** and **gene linkage** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.



Punnett squares

Geneticists often use **Punnett squares** to depict genetic crosses and to determine the probability of the offspring's being a particular genotype or phenotype. On the top of a Punnett square the *possible gametes* of the female are listed, and down the left side the *possible gametes* of the male are listed. The gametes are then combined in each of the boxes within the square to give the *possible gamete combinations* (the possible genotypes) of the offspring. On the left is the Punnett square for the man and woman with the free and attached earlobes described in the paragraph just above Review Questions 5B-1. Note that all their offspring, no matter how many they have, will have the father's phenotype, even though none of them have his genotype.

	f	f
F	Ff	Ff
f	ff	ff

Let us assume that one of the sons of the cross spoken of above married a woman with attached earlobes. The man's genotype must be *Ff*, and the

FACETS OF BIOLOGY

5B-1

The Key to Genetics–Fruit Flies

In the early twentieth century the tiny **fruit fly** captured the attention of the scientific world–not because of major crops it destroyed (this insect normally consumes small amounts of overripe fruit) or diseases it carried (it is rarely involved in transporting any disease). What caused some of the most brilliant scientists at major universities to begin spending countless hours and millions of dollars was this insect's genetics.

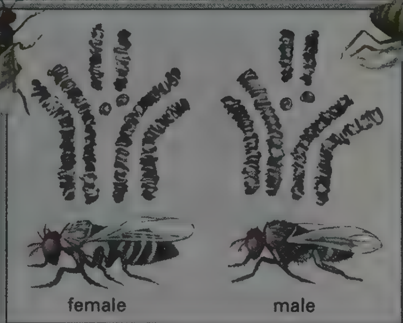
For several reasons scientists found *Drosophila melanogaster* (droh SAHF uh luh ◊ MEL uh noh GAS tur), the tiny fly often found around ripe fruit, ideal for genetic investigations.

❑ *Abundant offspring* One mating will produce hundreds of offspring, enough to show genetic ratios without waiting for additional matings.

❑ *Short life span* Fruit flies reach maturity in about 16 days. The F_2 generation can be reached in about a month. In many organisms a scientist must wait years for a characteristic (baldness, for example) to express itself even in the F_1 generation.

❑ *Ease of keeping and handling* Their size and temperament permit hundreds of them to be kept in a small bottle. A small amount of mashed fruit will feed them for their entire lives. Even the study of small laboratory animals like mice requires much more effort.

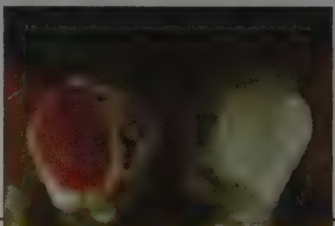
❑ *Noticeable differences* Unlike the sexes of many small organisms, fruit fly sexes appear different. They also have many contrasting traits which can be observed easily.



Karyotype of fruit flies

❑ *Four pairs of chromosomes* A small number of chromosomes makes the manufacture of karyotypes and the study of chromosomes and their behavior relatively easy.

Because of the ease with which these tiny insects can be studied, many of the genetic concepts which are accepted today were either verified by or originated with observations of fruit flies. Early in their study the idea that genes



Red eye (normal) and white eye of the fruit fly

Discovery of Sex-linked Traits

In 1910 Dr. Thomas Hunt Morgan noticed a single white-eyed fruit fly among the normal red-eyed fruit flies. This unusual male was quickly captured and placed with a virgin red-eyed female. All of the offspring had red eyes, and in the next generation, 75% had red eyes and 25% had white eyes. This led to the conclusion that the white-eyed characteristic must be recessive. But when examined, these flies revealed different attributes from the recessive characteristics previously observed. Only males had white eyes, but not all the males had white eyes. Two-thirds of the red-eyed individuals were female, and one-third were male. Repeated matings brought the same results.

Dr. Morgan proposed that the gene for this characteristic was on the *X* chromosome and not on the *Y*. Whenever the dominant (red-colored) gene was present on at least one *X* chromosome, the fly's eyes would be red. In theory, then, if a cross were made between a white-eyed male and a red-eyed female that carried the trait for white eyes on one of her *X* chromosomes, white-eyed females would result. When the experiment was performed, the predicted results occurred. The first *sex-linked* characteristic had been observed.

only genotype the woman could have is *ff*. Note the Punnett square for this couple earlier in this paragraph. One-half the boxes within the square have the dominant allele and will produce individuals with free earlobes, and 1/2 the boxes are homozygous for recessive alleles and will produce individuals with attached earlobes. Each child of these two individuals, therefore, will have a 50% chance of having attached earlobes and a 50% chance of having free earlobes.

If this couple were to have 12 children, the probability of 6 having free earlobes and 6 having attached earlobes is very good. Of course, if they have only 3 children, it will be impossible for them to express the expected 50/50 ratio. In fact, it is quite possible that all of this couple's children will have the same trait. *Each child* has a 50/50 chance for either trait.

Assume that two individuals who are heterozygous for earlobe attachment marry and have a child. What are the child's chances for attached earlobes? Make a Punnett square for this cross. (Check your square with the answer on page 141.)

The Punnett square has 1 homozygous recessive combination *(ff)*. Since the homozygous dominant *(FF)* and the 2 heterozygous *(Ff)* combinations will produce individuals with the dominant phenotype (free earlobes), the child has a

The ability to taste PTC, a chemical, is another easily determined simple dominant and recessive human trait. (PTC paper is available from biological supply houses.) Find out who has what characteristic and add a lively, "Now if Tom married Martha, what would we expect their children to be–tasters or nontasters?" This will definitely maintain interest. The student who does not yet understand is the ideal one to hypothetically "cross" with the sharpest-looking member of the opposite sex.

were located on a chromosome (a concept called **gene linkage** or *chromosome linkage*) was verified.

Because of the hundreds of thousands of crosses involving many generations that have been performed on these organisms, scientists were able to work out "chromosome maps" which tell the loci of various genes on the insect's chromosomes.

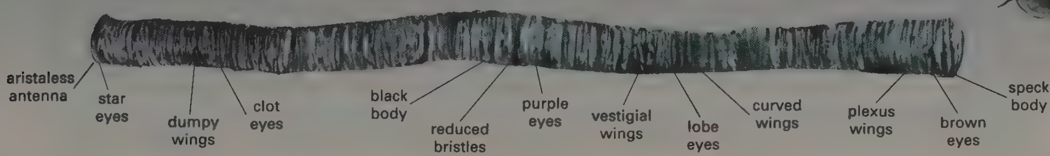
By doing karyotypes of fruit flies scientists verified the inheritance of sex by sex chromosomes. Fruit flies have 3 pairs of autosomes and 1 pair of sex chromosomes, and the inheritance of sex is similar to that in humans: *XX* is a female, and *XY* is a male. In fruit flies, as in many organisms (but unlike humans), the *Y* chromosome is slightly larger than the *X* chromosome.

Fruit flies have been exposed to various kinds and amounts of radiation and substances which have caused changes in their genetic information or *mutations*. Scientists have carefully tended flies with curly, wrinkled, and otherwise deformed wings; odd colors and shapes to their eyes; abnormal antennas; and various other conditions that would cause them to die in nature.

Through the study of the inheritance of these mutations and other characteristics, scientists have learned much about the mechanisms of genetics. Without the multiplied billions of fruit flies that have been bred, our knowledge of how traits are inherited would still be "waiting for results." But because of the ease with which scientists have been able to use the fruit fly for genetic experiments, we know more about this tiny insect's genes than we do about human genes.

Review questions on page 131.

A gene map of one of the three larger fruit fly chromosomes



Visual 5B-2 presents some simple genetics problems for classroom work. It is best to have students determine the genotypes from the given phenotype relatively early. To determine which is dominant and which is recessive, see chart on page 125.

Later, after introducing genetic crosses and Punnett squares, use the same questions, and ask students to determine ratios. Answers given below.

Answers–Visual 5B-2 (first part)

1. *YY × yy*

	Y	Y
y	Yy	Yy
y	Yy	Yy

2. *Yy × yy*

	Y	y
y	Yy	yy
y	Yy	yy

3. *Yy × Yy*

	Y	y
Y	YY	Yy
y	Yy	yy

4. *YY × Yy*

	Y	Y
Y	YY	YY
y	Yy	Yy

5. Impossible. No heterozygous green pea is possible.

Answers–Visual 5B-2 (second and third parts)

1. All *Yy*, all yellow; genotypic ratio–4 *Yy*:0; phenotypic ratio–4 yellow to 0 green
2. Half *Yy*, half *yy;* genotypic ratio–0 *YY*:2 *Yy*:2 *yy;* phenotypic ratio–2 yellow to 2 green
3. One-fourth *YY*, half *Yy*, one-fourth *yy;* genotypic ratio–1 *YY*:2 *Yy*:1 *yy;* phenotypic ratio–3 yellow to 1 green
4. Half *YY*, half *Yy*, all yellow; genotypic ratio–2 *YY*:2 *Yy*:0 *yy;* phenotypic ratio–4 yellow to 0 green
5. Impossible

This box contains supplemental material which should be studied by most students. Omit the box if time is limited. This box presents the design and use of pedigrees. Several of the activities in the Laboratory Manual involve the use of pedigrees.

The term **pedigree** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

See pedigree of hemophilia (p. 139). Also note information regarding the ethics and moral use of genetic information described in Chapter 6B.

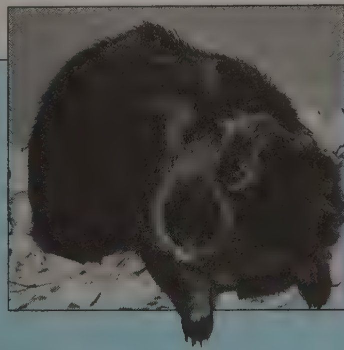
Visual 5B-3a may be used to teach students to solve basic genetic problems. Place the problem on the overhead, give the students time to work the problem on their own paper (while they do so, walk around, glancing over their shoulders), and then have them show how the problem is worked on the chalkboard, while they explain how to obtain the answer to each step. Then go on to the next problem. Answers are given below.

Visual 5B-3b may be used approximately the same way as 5B-3a. This set of problems, however, requires working backwards and thus demands additional thought. This is a good place to introduce the concept of a pedigree. ▶

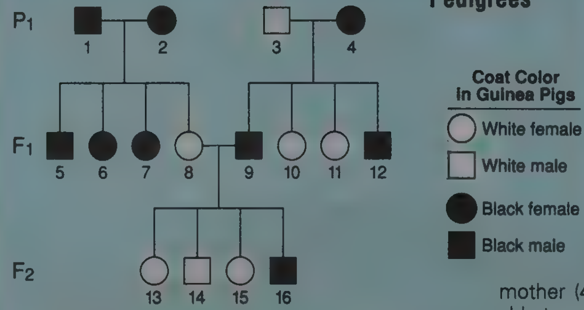
75% chance of having free earlobes. If the couple has 12 children, there should (statistically speaking) be 9 with free earlobes and 3 with attached earlobes. Of course, the ratios may not work out perfectly for *individual* families.

Genetic ratios in monohybrid crosses

The probability of offspring having or not having a particular gene or trait is usually expressed as a



Pedigrees



A **pedigree** is a chart which geneticists use to show the presence or absence of a trait in a number of generations. Pedigrees often use symbols to indicate sex, marriage (or matings of animals and plants), offspring, and other related factors. Phenotypes are often indicated by symbols, shading, or colors.

Note the pedigree of coat color in guinea pigs. In the P_1 generation individuals 1 and 2 have black fur but one of their offspring, number 8, has white fur. You should be able to determine that black is the dominant characteristic *(B)*, and that individuals 1 and 2 are heterozygous for the trait. This is determined as follows: since 8 must be homozygous for white fur *(bb)*, she must have inherited a recessive allele from both parents. But since both parents have black fur, they must also have the dominant allele. Thus 1 and 2 must be heterozygous *(Bb)*. (If you do not understand that, try working it on a Punnett square.)

Now try another. Individual 9 must be heterozygous. You can determine that by looking at his parents or by looking at his offspring. First, look at his parents. Because his father (3) has the recessive phenotype, the father must also have the recessive genotype *(bb)*. The father can give his son only a recessive allele, since that is all he has. Since the son has the dominant phenotype (black) he must be heterozygous *(Bb)*. He must have received the dominant allele from his mother (4), and since her coat is black, she is able to pass this trait on to her son.

Now determine the genotype of 9 by looking at his offspring. He is mated with a white female (8) who must have the genotype *bb*. Since three of their offspring are white, he must be able to give the recessive allele to his offspring, even though he must have the dominant allele to be black. Thus, he must be heterozygous *(Bb)*.

In this pedigree the genotypes can be determined for every individual except 5, 6, and 7. Geneticists would say there are "blanks" for these individuals. We know they have the dominant allele *(B)* but cannot be sure of the second allele. Their parents (1 and 2) are both heterozygous and thus can produce 2 different genotypes for black coats: *BB* and *Bb*. Some students think that since there are 4 boxes in a Punnett square from mating their parents *(Bb x Bb)* and since there are 4 offspring, each offspring must be one of the genotypes in the Punnett square. Remember that a Punnett square shows *possible* genotypes of the offspring in the ratio they are *expected* to occur. Based on the pedigree we cannot be sure of the genotypes of individuals 5, 6, and 7 without running test crosses.

Today geneticists create pedigrees to predict the possibilities of certain traits in offspring. Although not significant for many characteristics such as hair color and height, the information can be useful when it involves inherited disorders or diseases.

Answers–Visual 5B-3a

1. Genotype of parents–*II* × *ii*; gametes–*I* and *i*; gamete combinations–*Ii*; phenotypes–all inflated

2. *Ii* × *Ii*

	I	i
I	II	Ii
i	Ii	ii

phenotypic ratio–3 inflated to 1 constricted; genotypic ratio–1 *II*:2 *Ii*:1 *ii*

3. Yellow

	Y	Y
y	Yy	Yy
y	Yy	Yy

Y = yellow
y = green

4. Axial bloom; *Aa* × *Aa;* yes

	A	a
A	AA	Aa
a	Aa	aa

A = axial
a = terminal

Answers–Review Questions 5B-2

1. *Xx* × *Xx* yields one-fourth homozygous dominant *(XX)*, one-half heterozygous *(Xx)*, and one-fourth homozygous recessive *(xx)*; the ratio is expressed as 1:2:1 and explained with a Punnett square.
2. Three-fourths show the dominant trait and one-fourth show the recessive trait; therefore, 3:1 = dominant:recessive. The heterozygous organisms would have the same basic appearance as homozygous dominant because the dominant gene would determine the appearance.
3. Punnett squares determine the probability of an offspring's having a particular

ratio. Corn kernel color clearly illustrates genetic ratios since on each ear of corn there are enough individual kernels to present an accurate ratio. In corn the gene for purple kernels *(P)* is dominant over its allele for yellow kernels *(p)*. If pollen from a homozygous yellow plant is applied to the developing ear of a homozygous purple plant, the ear of corn will develop all purple kernels. The Punnett square indicates 4 boxes with the heterozygous genotype *(Pp)* and none with any other genotype. The genotypic ratio for the F_1 generation is 4:0, or 4 heterozygous *(Pp)* to none of the other 2 types. In this case the phenotypic ratio is 4:0, or 4 purple to none of any other type. (Usually such ratios are reduced to 1:0, but both are accurate.) In phenotypic ratios the number of dominant individuals is listed first. The F_2 generation of this cross, however, will have different ratios.

	P	P
p	Pp	Pp
p	Pp	Pp

PP x **pp**
ratios:
genotypic 4:0
phenotypic 4:0

When 2 heterozygous corn plants are cross-pollinated, the F_2 phenotypic ratio will be 3:1; that is, 3 purple kernels will occur for every 1 yellow kernel. The genotypic ratio, however, will be 1:2:1–that is, 1 homozygous dominant, 2 heterozygous, and 1 homozygous recessive. (Always list the number of homozygous dominant, then heterozygous, and then homozygous recessive individuals when giving this type of genotypic ratio.)

	P	p
P	PP	Pp
p	Pp	pp

Pp x **Pp**
ratios:
genotypic 1:2:1
phenotypic 3:1

5B-5 *This corn cob has the phenotypic radio of 3 purple to 1 yellow. Can you determine what the genotypes of the parents must have been?*

If a heterozygous plant is mated with a homozygous yellow plant, what will be the expected genotypic and phenotypic ratios? (See page 141.)

A test cross

How can you tell whether a genotype of a purple kernel of corn is *PP* or *Pp?* The best way for many organisms is to run a test cross to find the genotype of an individual. A **test cross** involves mating an individual that has the dominant phenotype but an unknown genotype with another individual that has the recessive phenotype. The individual with the recessive phenotype has a known genotype (homozygous recessive).

For example, if you mated a homozygous purple kernel plant *(PP)* with a yellow kernel plant *(pp*, the homozygous recessive), what would be the color of the offspring? All would be purple. If you mated a heterozygous purple kernel plant *(Pp)* with the same yellow kernel plant, what would be the color of the offspring? Half would be purple and half would be yellow. Thus by looking at the offspring of a test cross you can tell the genotype of the dominant parent (if you have *enough* offspring).

Review Questions 5B-2

1. Two organisms heterozygous for a single trait are crossed. What is the expected genotypic ratio of the offspring? Explain.
2. What is the phenotypic ratio of the cross described in question one? Explain.
3. What can a biologist learn by looking at a Punnett square for a cross?
4. Describe a test cross. What would a test cross be used to determine?
5. What information can a geneticist learn by looking at a pedigree for a cross?

Facet 5B-1: The Key to Genetics–Fruit Flies, pages 128-29

1. What characteristics of the fruit fly make it a useful organism for genetic studies?
2. List three genetic concepts that were discovered or verified by the study of fruit flies.
3. What is a chromosome map?
4. Name a sex-linked characteristic in fruit flies.
5. List two things that we can learn by observing a karyotype of a fruit fly.

▶ Often by diagramming these crosses as pedigrees, students are able to grasp not only the idea of a pedigree but also how to solve these problems. Answers are given on page T33.

Sample problems require a "test cross" concept. In humans a cleft chin is dominant. Bob, who has a cleft chin, marries Sue, who has a smooth chin. Their son has a cleft chin. What is Bob's genotype? *(don't know)* His second son also has a cleft chin. Now what is Bob's genotype? *(still don't know)* Their third child, a daughter, has a cleft chin. What is Bob's genotype? *(don't know)* Could one venture a guess? *(He probably is homozygous, but one cannot be sure.)*

George, who has a cleft chin, marries Mary, who has a smooth chin. Their first son has a smooth-chin. What is George's genotype? *(It must be heterozygous.)* Consider Bob and Sue again. How could one be sure of Bob's genotype? *(The more cleft-chinned children he has, the more likely it is that he is homozygous. One smooth-chinned child, however, proves he is heterozygous.)*

Visuals 5B-4a and **b** may be used to teach solving pedigree problems. Answers are given on page T34.

Visual 5B-5 can be used to teach the concept of test crosses. Answers are given on page T34.

genotype or phenotype. They describe possible gamete combinations.

4. In a test cross, an individual with the dominant phenotype but unknown genotype is crossed with an individual possessing the recessive phenotype. By looking at Punnett squares and the probabilities of certain genotypes, the unknown genotype can possibly be determined; a recessive genotype can occur only if the unknown is heterozygous.

*5. Using a pedigree, one should be able to determine dominant and recessive characteristics, the phenotypes of the individuals (given), the matings and offspring (given), and genotypes of many (if not all) individuals.

*From a box.

Answers–Facet 5B-1

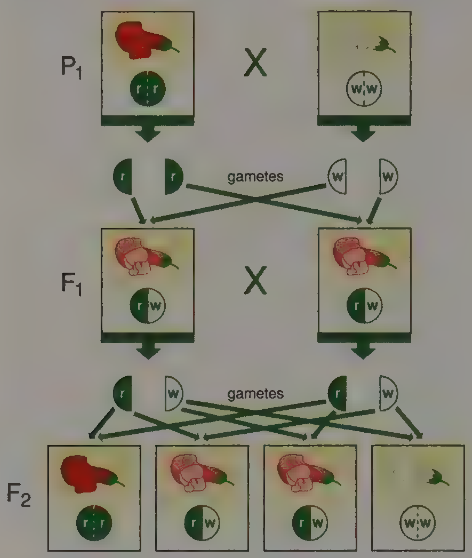
1. Abundant offspring, short lifespan, ease of keeping and handling, noticeable differences, 4 pairs of chromosomes
2. Gene linkage, sex linked characteristics, mutation (harmful nature), inheritance of sex
3. A diagram or sequential listing of the genes on a particular chromosome
4. Red and white eyes
5. **(1)** That fruit flies have 4 pairs of chromosomes (2n = 8); **(2)** the sex of the individual, because the fruit fly's *Y* chromosome is larger than the *X* chromosome

After students have mastered the concepts of dominant and recessive, present the exception. Stress the difference between incomplete dominance and the concepts the students have just studied.

To illustrate the concept, work out some hypothetical pedigrees and Punnett squares for families with brachydactyly or sickle cell anemia.

Variations of Mendelian Genetics

If the Mendelian concepts studied thus far were the only factors involved in heredity, the prediction of probable phenotypes would be easy. Although genetics is based largely on the concepts illustrated in a monohybrid cross with simple dominant and recessive characteristics, there are many variations. These variations, although simple, make predictions of an organism's phenotype quite difficult. Many human traits, including sex, eye color, height, skin color, blood type, and intelligence, as well as a number of disorders, are determined by these genetic mechanisms.



5B-6 *Incomplete dominance in snapdragon color*

Incomplete dominance

Not all genetic traits are dominant or recessive. Many alleles express **incomplete dominance.** Flower color in snapdragons and other common garden flowers demonstrates this condition. When a homozygous red and a homozygous white snapdragon are crossed, all the offspring are pink.

	r	r
w	rw	rw
w	rw	rw

rr × ww

ratios:
genotypic 1:0
phenotypic 1:0

In snapdragons neither red nor white is dominant, and in a heterozygous flower both alleles express themselves in the pink color. Crossing 2 pink snapdragons yields 1/4 white, 1/2 pink, and 1/4 red snapdragons.

	r	w
r	rr	rw
w	rw	ww

rw × rw

ratios:
genotypic 1:0
phenotypic 1:0

Note that in the Punnett square 2 different letters represent the alleles. Using capital and lowercase letters might make it appear that the alleles are dominant and recessive. It has become conventional to use different letters when crossing incompletely dominant alleles.

Pages 154-55 have more information about sickle cell anemia. Many are confused about this disease. It does not affect all black people, nor is it contagious among them. Although it is not common among white people, they can have this disease if their family carries the gene. Occasionally, mutation is believed to introduce the gene into a family.

Many human traits appear to be the result of incomplete dominance. People who suffer from *brachydactyly* (BRAK ih DAK tuh lee) lack a bone in each finger and toe and therefore have abnormally short fingers and toes. A person with brachydactyly is heterozygous (that is, he has 1 abnormal gene and 1 normal gene); people with normal fingers and toes are homozygous for the normal gene; and people that are homozygous for the brachydactyly gene are severely crippled, with a complete lack of fingers and toes.

It appears that some individuals who are homozygous for the sickle cell trait do not survive until birth.

Another human trait which appears to be incompletely dominant is *sickle-cell anemia.* Most people in the United States are homozygous for the production of normal hemoglobin. Those people who are heterozygous for sickle-cell anemia produce normal and abnormal hemoglobin. Red blood cells which contain abnormal hemoglobin can become sickle-shaped rather than round and disc-shaped. The blood of heterozygous people contains both round and sickle-shaped cells. Their blood cannot carry as much oxygen as normal blood can.

Visual 5B-6 can be used to teach the concept of incomplete dominance. Answers are given below.

When people carry on strenuous activities or are in high elevations, they undergo oxygen stress. If a person heterozygous for sickle-cell anemia is under oxygen stress, some of his red blood cells will become sickle-shaped. In this unusual shape the blood cells may not be able to carry all the oxygen that the body tissues need. About 1 in 12 black Americans is heterozygous for the abnormal hemoglobin and has what is

Answers–Visual 5B-6

1. *rr* × *yy*

	y	y
r	yr	yr
r	yr	yr

2. *ry* × *ry*

	y	r
y	yy	yr
r	yr	rr

Genotypic ratio–1 *rr*:2 *ry*:1 *yy*; phenotypic ratio–1 red:2 broken:1 yellow

3. A pure strain of *ry* cannot be obtained. When *ry* is mated with anything *(rr, yy,* or *ry),* the results will not be all *ry.* The only way to obtain all *ry* individuals is to mate *rr* and *yy* and plant those seeds.
4. **(a)** Black agouti is heterozygous *(ba* or *ab),* black is homozygous *(bb),* and albino is homozygous *(aa).* (Students may use other letters. The combinations are important.)
(b) *ba* × *ba* (or *ab* × *ab)*
(c) Black agouti–*ba (ab);* black–*bb;* albino–*aa*
(d)

	b	a
b	bb	ba
a	ba	aa

(e) Yes

5B-7 *Blood being tested for sickle-cell anemia. Normal blood (left) and sickle-cell blood (right).*

called the *sickle-cell trait*. These people can carry on nearly normal life-styles if they eat properly and get sufficient rest.

About 3 black children per 1,000 born in America are homozygous for abnormal hemoglobin. All their cells are sickle-shaped. This abnormal blood results in aching bones and clogged blood vessels in the spleen and lungs. Although blood transfusions can prolong their lives, these people usually die as children.

Multiple alleles

The traits we have discussed thus far have had 2 contrasting alleles. In peas there is the allele for the tall trait and the allele for the short trait. In sickle-cell anemia there is the allele for normal hemoglobin and the allele for abnormal hemoglobin. The place on a chromosome where a particular gene is located is the gene's **locus*** (pl., loci). The alleles for the traits of a monohybrid cross appear at the same loci on the homologous chromosomes. Since chromosomes in peas and humans and all diploid organisms occur in pairs, there are two of most of their alleles. One of these 2 will be at each locus.

Occasionally, however, there may be **multiple alleles**–that is, 1 of several alleles can be at a given locus. A diploid organism, of course, will have only 2 of the possible alleles–1 on each of the homologues. If there are, then, incompletely dominant alleles for yellow, red, and white flowers, all colors possible at the same loci, new colors

pink

yellow	r	w
y	ry orange	wy cream
y	ry orange	wy cream

alleles:
r red
w white
y yellow

rw × yy

ratios:
genotypic 2:2
phenotypic 2:2

(oranges and creams) will be possible.

A simple multiple allele condition in humans is the A and B blood types. There is 1 allele for the factor causing blood type A and 1 allele for the factor causing blood type B, both of which are dominant. There is a recessive allele for no factor. In diagramming this multiple allele cross, it is traditional to use the capital letter I to represent the chromosome and a superscript to represent the dominant alleles. I^A and I^B are then dominant alleles. The recessive allele, neither A nor B but recessive to both, is represented by the letter i.

	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

$I^Ai \times I^Bi$

A person with blood type A could be homozygous (I^AI^A) or heterozygous (I^Ai); and someone with type B could be I^BI^B or I^Bi. A person can be heterozygous for *both* dominant alleles (I^AI^B) and have blood type AB. Someone homozygous for the recessive trait (ii) has type O.

Let us use this information to solve a hypothetical problem. Both Mrs. Pearson and Mrs. Brown had baby girls the same day in the same hospital. The Pearsons named their daughter Sally, and the Browns named their daughter Barbara. At home Mrs. Pearson began to feel that Sally was not her daughter. Perhaps there had been some mix-up in the hospital nursery.

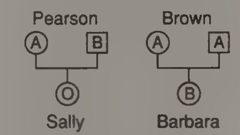
Blood tests were made. Mr. Pearson was type B, Mrs. Pearson type A. Mr. Brown was type A, Mrs. Brown type A. Sally was type O, and Barbara was type B. Had a mix-up occurred? Draw Punnett squares to illustrate the genotypes of these people. The answer is diagrammed and explained on page 141.

Some other human blood types and characteristics are believed to be determined by multiple alleles. Coat color and patterns in many mammals are determined by multiple alleles.

locus: (L. LOCUS, place)

Stress the fact that *multiple alleles* means that there are more than 2 possible alleles that the individual *could* have, not that he actually has. Each individual has only 2. Some traits have more than the 3 alleles given in these examples.

Draw a pedigree to illustrate the Brown and Pearson example.



Visual 5B-7 can be used to demonstrate multiple alleles. The third problem involves a paternity suit. A paternity suit (in which a woman claims that a man is the father of a child and thus should take some legal responsibility for the child–usually by paying child support) should not happen in Christian circles. To claim that paternity suits do not happen among non-Christians is to ignore reality. There is nothing wrong with students' knowing information about paternity suits and the limitations of the value of blood-type information in paternity suits. The teacher will probably need to define a paternity suit and should at that time point out that these problems would not exist if everyone practiced the moral code established in the Scripture. Some teachers may wish to omit the third problem on this sheet rather than to take the time to discuss the morality involved with the issue. Answers are given below.

Answers–Visual 5B-7

1. $I^Ai \times I^Bi$

	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

(a) Yes
(b) Yes

2. $ii \times I^AI^B$

	i	i
I^A	I^Ai	I^Ai
I^B	I^Bi	I^Bi

(a) No
(b) No
(c) A or B

3.

	I^B	_
I^B	I^BI^B	I^B_
_	I^B_	__

(a) This man could not have a child with type A blood by this woman.
(b) If the child had been B, it would not have proved this man the father.
(c) This is possible only in certain cases in which the blood types are not compatible.

dihybrid: di- (two) + -hybrid (offspring of different parents)

Review Questions 5B-3

1. Compare simple dominance with incomplete dominance. List several characteristics that exhibit incomplete dominance.
2. Describe the condition of multiple alleles. What human characteristics are controlled by multiple alleles?

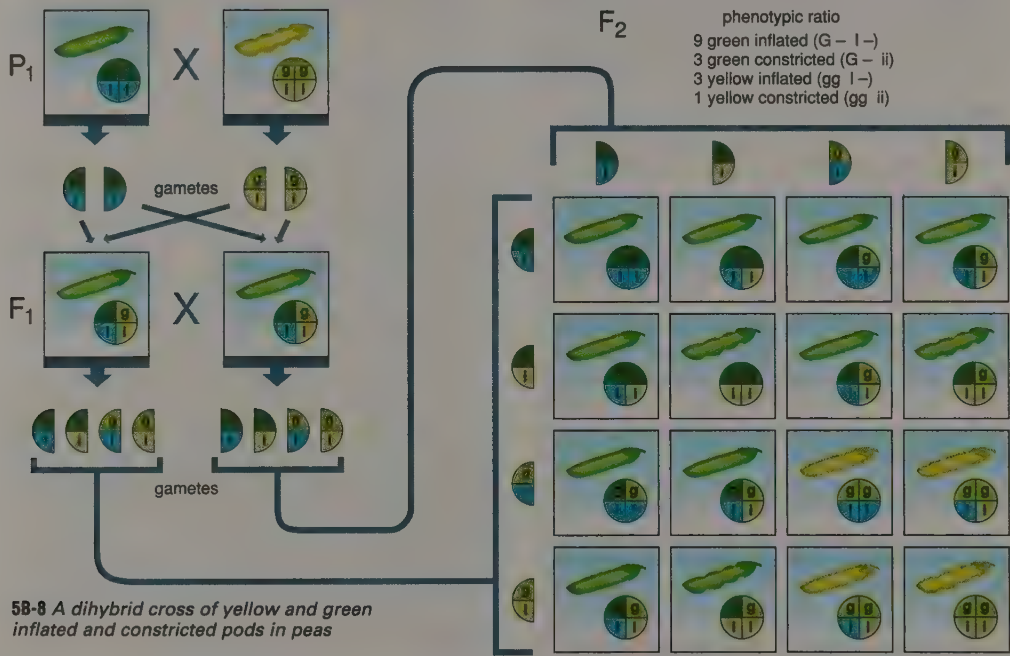
Consider illustrating a dihybrid cross but telling students they will not be expected to do one for a test. This should be presented to lower-level students only to show the potential complexity of genetic crosses. Let the advanced students be aware of this, but do not force understanding on lower-level students. Omit material about dihybrid crosses through multiple gene interaction if time is limited.

Dihybrid crosses

A **dihybrid*** **cross** deals with 2 sets of characteristics at the same time. Study figure 5B-8, which is the crossing of a homozygous green, inflated-pod pea plant *(GGII)* with a homozygous yellow, constricted-pod pea plant *(ggii)*.

Since we are now dealing with 2 characteristics, we must consider 4 alleles, 2 for each characteristic. When gametes are made, however, the alleles segregate, and only 1 allele for each characteristic will be in each gamete. Since chromosome pairs separate, there will normally not be a gamete containing 2 alleles of 1 gene and none of the other. The forming of the F_1 by the uniting of the gametes results in individuals that have green, inflated pods. They are, however, heterozygous for both traits.

The formation of gametes in the F_1 results in four different possibilities: *GI*, *Gi*, *gI*, and *gi*. (Under normal circumstances a *Gg* gamete or an *Ii* gamete would not occur because segregation of chromosomes in gamete formation separates the alleles, making the gametes haploid.) The procedure for finding the possible gamete combinations for the 2 traits is much the same as for finding the possible combinations in a monohybrid cross: list the possible gametes from the male on the side of, and the possible gametes from the female on the top of, a Punnett square. Since there are 4 possible gametes from each parent, the Punnett



5B-8 *A dihybrid cross of yellow and green inflated and constricted pods in peas*

Visual 5B-8 can be used to help teach and reinforce the concept of dihybrid crosses. The duck problem is hypothetical. Answers are given below.

Answers–Review Questions 5B-3

1. Simple dominance occurs when the dominant gene in a heterozygous organism yields the dominant phenotype; incomplete dominance occurs when two different homozygous organisms are crossed, producing heterozygous organisms that exhibit neither the dominant nor the recessive characteristic but a combination of the two. Sickle cell anemia and brachydactyly in humans and pink color (red and white) in some plants result from incomplete dominance.
2. *Multiple alleles* refers to a condition in which one of several alleles can occupy a given locus. Blood types are caused by multiple alleles.

Answers–Visual 5B-8

1. *RRTT* × *rrtt*, gametes *RT*, *rt;* genotypic ratio–1 *RrTt*:0; phenotypic ratio–1 round tall:0 anything else
2. *RrTt* × *RrTt*

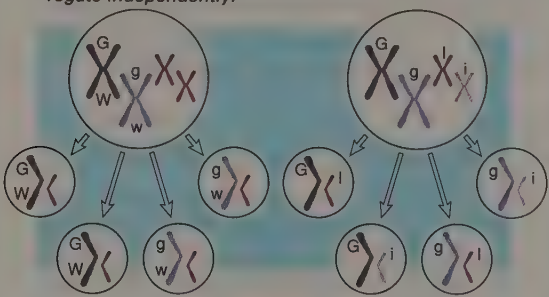
	RT	Rt	rT	rt
RT	RRTT	RRTt	RrTT	RrTt
Rt	RRTt	RRtt	RrTt	Rrtt
rT	RrTT	RrTt	rrTT	rrTt
rt	RrTt	Rrtt	rrTt	rrtt

3. *TTrr* × *TTrr*
One cannot tell by looking whether it is *TTrr* or *Ttrr*. Performing test crosses on *TTrr* or *Ttrr* will tell which one is

square for this cross must have 16 blocks. The phenotypic ratio of individuals within the Punnett square is 9 green inflated; 3 green constricted; 3 yellow inflated; and 1 yellow constricted.

Assume that a plant breeder is interested in obtaining a homozygous strain of green constricted peas. In the F_2 Punnett square there are 3 boxes that contain individuals of this phenotype. You will notice, however, that there are, for this phenotype, 2 different genotypes: *GGii* and *Ggii* (1 homozygous and 1 heterozygous for green). How can he tell the difference between them? He cannot do so simply by looking at the peas. One way he *can* find out is to test cross the peas in question. Draw a Punnett square for the 2 possible test crosses to see what you would expect from each of the 2 genotypes. The answer is on page 141.

5B-9 *The G/g alleles are on one chromosome, and the I/i on another (right); thus, they segregate independently of each other. The G/g and the W/w alleles are on the same chromosome (left) and thus do not segregate independently.*



Mendel's concept of independent assortment

Mendel himself used dihybrid crosses, and the results of those crosses led him to formulate his **concept of independent assortment:** the segregation (separation) of 1 set of alleles during gamete formation is not affected by the presence or segregation of another set of alleles. When Mendel was observing 2 sets of characteristics in the same cross, he noted not only that the ratios he was expecting did result but also that these characteristics randomly mixed with the other characteristics. For example, the separating of the green-yellow alleles did not affect the separating of the inflated-constricted alleles. Green color will not always accompany constricted pods or inflated pods. The traits mix and match freely.

There is a logical exception to this concept, though Mendel did not encounter it in his work with garden peas. If the genes for 2 traits are on the same chromosome, they will not segregate independently as in a typical dihybrid cross (see figure 5B-9). All 7 characteristics Mendel observed were on different chromosomes and were, therefore, segregated independently. The pea has only 7 pairs of chromosomes, though. If Mendel had observed an eighth pair of contrasting characteristics, the "factors" would not have segregated independently, and he might have become confused.

Multiple gene interaction

A single characteristic is not always caused by a single gene. Sometimes 2 or more genes working together result in a single trait, a process called **multiple gene interaction.** One simple example of this is the combs of chickens.

A rose comb is caused by having a dominant gene at a locus and 2 recessive genes at another locus *(RRpp, Rrpp)*. A pea comb is caused by exactly the opposite *(rrPP* or *rrPp)*. A walnut comb results from having at least a dominant allele in each pair *(RRPP, RRPp, RrPP,* or *RrPp)*.

P_1 RRpp (rose) × rrPP (pea)

F_1 RrPp (walnut) × RrPp (walnut)

F_2

walnut → ↓	RP	Rp	rP	rp
RP	RRPP (walnut)	RRPp (walnut)	RrPP (walnut)	RrPp (walnut)
Rp	RRPp (walnut)	RRpp (rose)	RrPp (walnut)	Rrpp (rose)
rP	RrPP (walnut)	RrPp (walnut)	rrPP (pea)	rrPp (pea)
rp	RrPp (walnut)	Rrpp (rose)	rrPp (pea)	rrpp (single)

5B-10 *Multiple gene interaction in the combs of chickens*

The example described in the first full paragraph of the left column makes an excellent chalkboard illustration of dihybrid crosses. If students can follow this, they understand enough about dihybrid crosses for the general biology level. Consider giving a similar example using another set of characteristics.

A good method to help students understand Mendel's concept of independent assortment is to start with a review of meiosis and to work through to the idea of genes' being on the same chromosome or on another pair of chromosomes. Because some students find this difficult, it is good to present this quickly, permitting good students to grasp it but not belaboring the point for the poor ones.

Mendel has come under criticism because he did observe more than the seven pairs of contrasting characteristics he reported in his paper. Some feel he chose to ignore the results that did not support his hypothesis.

pure for the tall trait. *(TTrr × ttrr* or *Ttrr × ttrr)*

4. *ggAA × GGaa*

	GA	Ga	gA	ga
GA	GGAA	GGAa	GgAA	GgAa
Ga	GGAa	GGaa	GgAa	Ggaa
gA	GgAA	GgAa	ggAA	ggAa
ga	GgAa	Ggaa	ggAa	ggaa

The F_1 generation would all be *GgAa*. The F_2 generation is diagrammed in the Punnett square. Only 1 of the 16 possible offspring has the *GGAA* genotype, but 9 are green with axial flowers. Keeping accurate records and doing test crosses will be necessary to determine which of the individuals with the proper phenotype has the desired genotype.

5. *B* = big; *b* = small; *W* = white; *w* = brown. *BBww × bbWW = BbWw* (all big and white but not pure)

BbWw × BbWw

	BW	Bw	bW	bw
BW	BBWW	BBWw	BbWW	BbWw
Bw	BBWw	BBww	BbWw	Bbww
bW	BbWW	BbWw	bbWW	bbWw
bw	BbWw	Bbww	bbWw	bbww

Of the 16 possible gamete combinations, 9 appear big and white, but only 1 of them *(BBWW)* can be used to produce a pure strain. Of 64 ducks in the F_2, 36 should be big and white. Only by test crosses and keeping records for several generations can one be sure of the organisms' genotypes. This is why livestock known to have the desired characteristics is expensive.

If students seem overwhelmed at this point, multiple gene interaction is the material to omit. Some find it exceptionally confusing, even though it is merely a logical summation of other things they have learned.

The important concept regarding multiple gene interaction is that many human characteristics are caused by this mechanism. This explains the great difficulty with predicting such things as intelligence, height, or hair color and with understanding why some unexpected traits appear in families.

And a single comb is the result of having homozygous recessive alleles at both loci *(rrpp)*. Because there are 2 sets of genes involved in determining combs in chickens, they must be dealt with as dihybrid crosses. The 9:3:3:1 ratio is the same, but there are not 2 characteristics–just 1; and that one is the type of comb. There are, however, 4 types of combs.

Most human traits have some degree of multiple gene interaction. It seems, for example, that 5 or 6 gene pairs at different loci determine human skin color. The Punnett square for such a large number of gene possibilities requires over 100 different blocks and has dozens of different genotypes and phenotypes. Some of the gene pairs seem to be incompletely dominant, and some work as *inhibitors* (genes which prevent the expression of other genes). It is also possible that 2 or more of these genes are on the same chromosome and thus further confuse matters.

Humans produce very few offspring, and relatively poor records have been kept of the exact shade of skin color for more than a few generations. Knowing a person's genotype and predicting his child's phenotype for skin color are almost impossible.

5B-11 *At one time the chromosome was thought to be a nonchangeable unit. Today, scientists routinely manipulate chromosomes and genes.*

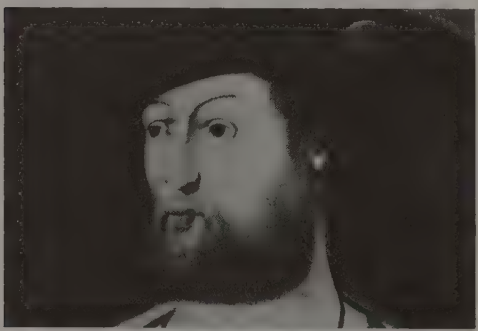
Hair color and eye color are similar but probably involve few gene pairs. Multiple gene action determines, in part, one's height, body build, intelligence, and many other human characteristics.

Review Questions 5B-4

1. Describe the concept of independent assortment. What condition could cause this principle not to work?
2. Describe multiple gene interaction and distinguish between it and multiple alleles.

Sex Determination and Sex-Linked Traits

King Henry VIII of England is remembered for his disappointment at having only one male heir.



5B-12 *Henry VIII of England*

When a wife did not bear him a son, he disposed of her and married again. But Henry VIII should probably have been more upset with himself: it is the man's genes that determine the child's sex.

Use the human karyogram on page 117 to show autosomes and sex chromosomes in humans.

Sex chromosomes and autosomes

Karyotypes reveal that normal people have 22 pairs of **autosomes** and 1 pair of **sex chromosomes.** The autosomes are non-sex-determining chromosomes and are traditionally numbered. The sex chromosomes are not numbered but in humans are designated *X* and *Y*. In humans the *Y* chromosome is considerably smaller than the *X* chromosome. A person with 1 *X* and 1 *Y* chromosome is male; a person with 2 *X* chromosomes is female.

During meiosis in females, the 2 *X* chromosomes pair; in the male the *X* and the *Y* chromosomes pair. Crosses of *X* and *Y* chromosomes can

Answers–Review Questions 5B-4

1. The segregation of one set of alleles during formation is not affected by the presence or segregation of another set of alleles. The traits mix at random. However, if the genes for two traits are on the same chromosome, they will not separate independently.
2. Multiple gene interaction involves the interaction of two or more genes to produce a single trait. In contrast, multiple alleles are several alleles that may be at a given locus. The phenotype depends on which allele is at the locus.

therefore be determined on a Punnett square. Note that only the father can give a Y chromosome to his offspring. Since it takes a Y chromosome to form a male offspring, the father thus determines the sex of the child.

male \ female	X	X
X	XX	XX
Y	XY	XY

XX × XY

According to the Punnett square there is a 50/50 chance of each child being a boy. Statistics show, however, that there are actually more boys born. Recent evidence shows that a Y sperm and an X sperm are probably slightly different in their reaction to various chemicals. The chemical make-up of the fluids in a female's reproductive structures varies amongst women and changes regularly in each woman. These differences could account for the slight difference between the expected ratio and the actual ratio of girls to boys. Henry VIII might have been able to blame his lack of many sons on the chemical make-up of 1 wife, or maybe 2; but to have had 6 wives and only 1 surviving son was probably not the fault of all the queens.

Sex-linked traits

The alleles found on autosomes are in pairs. Since autosomes are in pairs, the gene found at a particular locus on one will have a companion gene at the same locus on the homologue. At that locus there may be the exact same gene (homozygous condition) or a variation of that gene (heterozygous condition). But on sex chromosomes conditions may vary. In humans, for example, the X chromosome is much larger than the Y chromosome and thus can contain many more genes.

About 5% of the white males in northern Europe have a reduced amount of a chemical in the retina of their eyes that causes them to be *red-green colorblind.* To them most greens appear tan, olive greens appear brown, and most reds appear reddish brown. The condition is a recessive characteristic which is found on the X chromosome but does not have a companion allele on the Y chromosome.

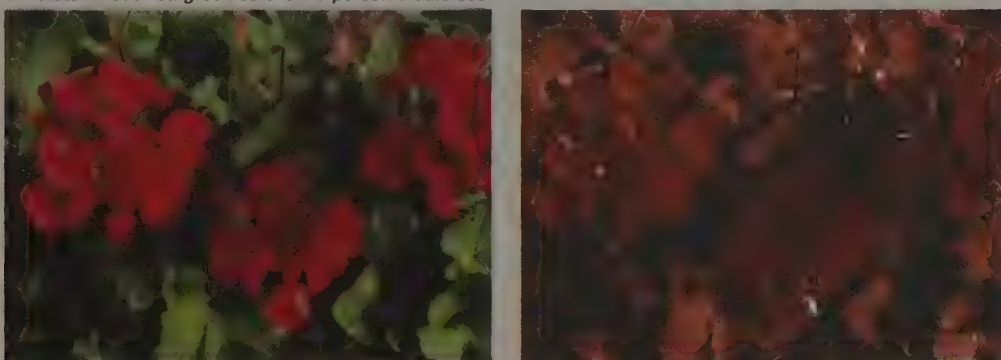
In order to diagram these crosses and keep straight the sex of the individuals, we will use the X and Y to indicate the chromosome and add superscripts to indicate the genes. Thus X^G is for a female sex chromosome that has the gene for normal vision; X^g is for a female sex chromosome that has the gene for red-green colorblindness; and Y is for the male chromosome. Since the male chromosome does not have a gene for this trait, it does not have a G or a g on it.

Traits which have their genes on the X chromosome and not on the Y chromosome are called **sex-linked traits** because they are linked to the sex of the individual. For example, on a Punnett square, cross a female who lacks the recessive trait with a male who is red-green colorblind. Note the sex of the offspring.

Would it be possible to get a family of only colorblind people? *(yes)* If the mother *(X^gX^g)* and father *(X^gY)* were both colorblind, all the offspring would have to be colorblind.

Visual 5B-9 presents some problems about sex-linked traits. Answers are given below.

5B-13 *The left picture is what a person with normal vision would see. The right picture has been adjusted to simulate what a red-green colorblind person would see.*



Answers–Visual 5B-9

1. (a) X^RY; (b) X^RX^R; (c) X^RX^r; (d) X^rY; (e) X^rX^r; (f) impossible
2. $X^RY \times X^rX^r$

	X^r	X^r
X^R	X^RX^r	X^RX^r
Y	X^rY	X^rY

All females have red eyes *(X^RX^r)*; all males have vermilion eyes *(X^rY)*.

3. Yes. $X^RY \times X^RX^r$

	X^R	X^r
X^R	X^RX^R	X^RX^r
Y	X^RY	X^rY

4. $X^rY \times X^rX^r$ or $X^rY \times X^RX^r$
5. Yes. $X^rY \times X^rX^r$

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents the characteristics and inheritance of a sex-linked blood disorder–hemophilia–in a historical setting.

The term **hemophilia** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Hemophiliacs often require blood transfusions when they are injured or have certain other difficulties. When the blood supply was contaminated with AIDS, some hemophiliacs became unfortunate victims of the disease. Now careful screening of donated blood helps to keep the blood supply free of most diseases (see *AIDS* and *hemophilia* in the Index).

Tzar Nicholas and Tzarina Alexandra of Russia were grieved by their son Alexis's condition and were manipulated by the power-hungry monk Rasputin for political advantage. This manipulation was instrumental in the decline of dynastic rule in Europe and the establishment of the modern Russian government. Note the enormous effect of a single mutant allele. Consider working Punnett square crosses of Tzar Nicholas and his children as examples.

The Royal Disease–Hemophilia

Hemophilia (HEE muh FIL ee uh) is sometimes called "bleeder's disease." People who have this genetic disorder lack a blood chemical that is essential for blood clotting. Even a small cut, therefore, can result in severe bleeding or death. Bumps, which for most people result in bruises, can cause internal bleeding, swelling, and possibly death for hemophiliacs. In times past, hemophiliacs usually died very young. Today, medication can supply the missing blood chemical.

Hemophilia has been found to be a sex-linked recessive trait. Although there are very old records of people who are believed to have been hemophiliacs, the best known historical record of the disease involves the royal house of Great Britain. Hemophilia has thus been called "the royal disease." Queen Victoria (reign 1837-1901) was a carrier of this sex-linked trait.

The pedigree on the next page shows only some of Queen Victoria's offspring. Her son Leopold was a hemophiliac. At a time when most hemophiliacs died as infants or young children, he was exceptionally protected and lived to maturity. Although his brothers joined and commanded British military regiments, Leopold was not even permitted to wear a uniform. A record of Leopold's life is one of "falling ill," as his mother

The British royal family (about 1860) with carriers indicated. Left to right: Alfred, Prince Albert, Helena, Arthur (in kilt), Alice, Beatrice (infant), Queen Victoria (seated), Princess Victoria, Louise, Leopold (facing camera) and Edward.

	X^H	X^H
X^h	X^HX^h	X^HX^h
Y	X^HY	X^HY

X^hY × X^HX^H

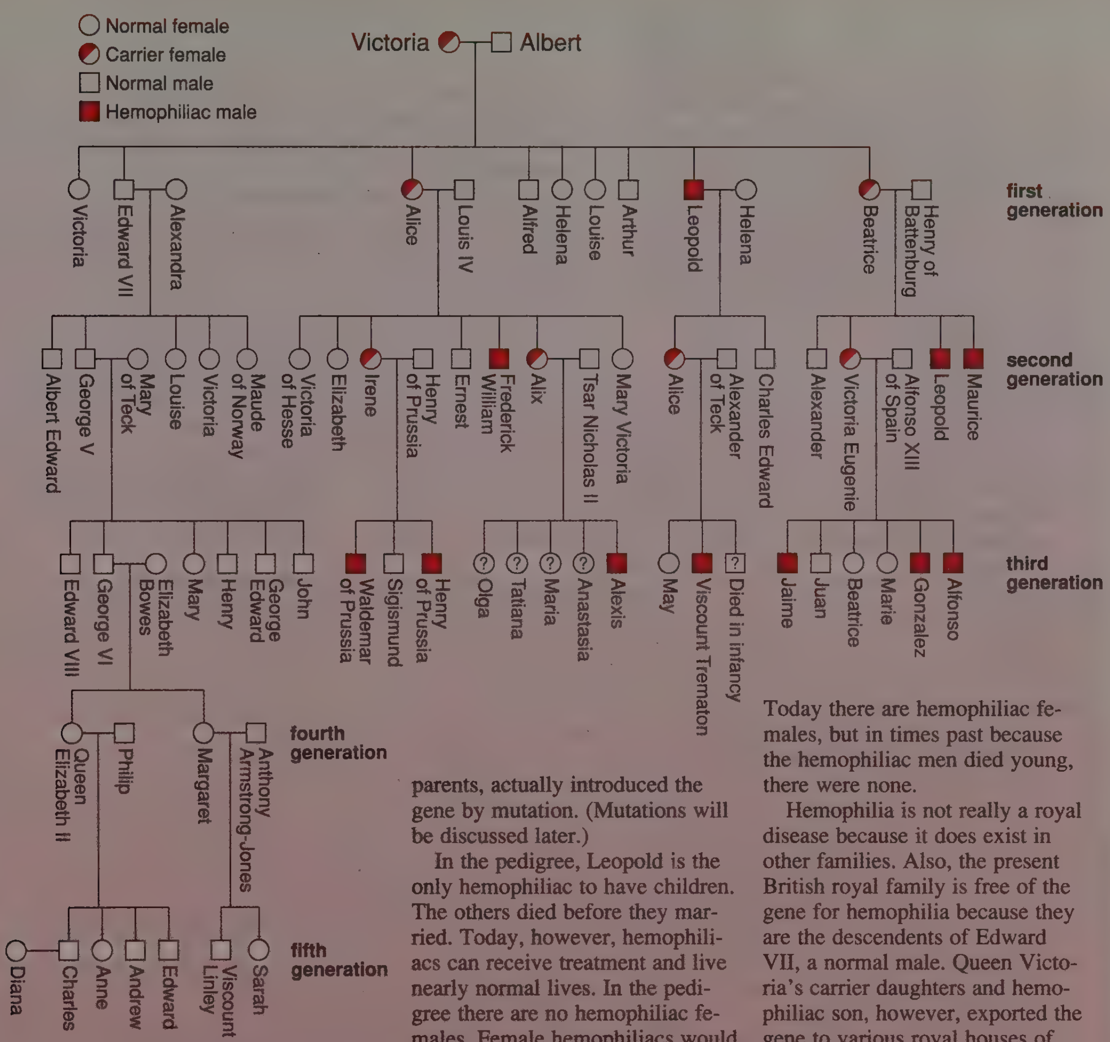
Leopold   Helena

put it, and spending long days in bed recovering.

After thwarting most of his attempts to be married, the Queen relented and arranged for Leopold's marriage to the German princess Helena of Waldeck. After a year Alice was born. A Punnett square for Leopold and Helena (see above) shows that their daughters could not be hemophiliacs but would be carriers. This fact is also demonstrated by Alice's offspring.

The second child of Leopold and Helena was a normal son, Charles Edward. Since Leopold must give the Y chromosome to any son, he could not give the gene for hemophilia to any of them. Leopold, however, did not know this and also did not know whether his second child was a hemophiliac or not. At age 31, before his son was born, Leopold hurt his knee and died of internal bleeding within a few days.

Queen Victoria was quoted as saying that hemophilia "was not in our family," and she was correct: no one on her side of the family expressed the recessive characteristic. She supposed that her husband, Albert, introduced



the disease into their lineage, but she was wrong. It is believed that Queen Victoria, or possibly her parents, actually introduced the gene by mutation. (Mutations will be discussed later.)

In the pedigree, Leopold is the only hemophiliac to have children. The others died before they married. Today, however, hemophiliacs can receive treatment and live nearly normal lives. In the pedigree there are no hemophiliac females. Female hemophiliacs would only be possible if a hemophiliac male married a woman who had the hemophiliac gene (a carrier).

Today there are hemophiliac females, but in times past because the hemophiliac men died young, there were none.

Hemophilia is not really a royal disease because it does exist in other families. Also, the present British royal family is free of the gene for hemophilia because they are the descendents of Edward VII, a normal male. Queen Victoria's carrier daughters and hemophiliac son, however, exported the gene to various royal houses of Europe.

Review questions on page 140.

Visual 5B-10 is the pedigree of Victoria and Albert regarding hemophilia. Use this to discuss the inheritance of hemophilia and to construct sample problems for the students to solve.

There are a few traits that are found on the Y chromosome which are not found on the X chromosome. One of these is the presence of long hair near the opening of the ears. This trait is passed from father to son, never to daughter. This trait occurs in certain tribes in India, but the hair is usually trimmed, and thus the trait is not commonly noticeable.

It appears that genes on the sex chromosome have very little to do with secondary sex characteristics (e.g., breast development, facial hair, or muscular build; see p. 609). These are sex-limited characteristics (discussed on p. 151).

A normal female and a red colorblind male

$X^G X^G \times X^g Y$

	X^G	X^G
X^g	$X^G X^g$	$X^G X^g$
Y	$X^G Y$	$X^G Y$

None of the sons have the trait because they get their X chromosome from their mother and their Y chromosome (which does not carry genes for this trait) from their father. None of the daughters are red-green colorblind either, because they are heterozygous for a recessive trait ($X^G X^g$). The daughters, however, are **carriers** of the red-green colorblindness trait. A carrier for a sex-linked trait is an individual that does not have the characteristic but does carry the gene for the trait.

Is it possible for a man to pass sex-linked traits on to his son? No. A man will always give the Y chromosome, which lacks genes for sex-linked traits. If a boy is red-green colorblind he inherited the characteristic from his mother.

Is it possible for a woman to be red-green colorblind? Yes. She must, however, be $X^g X^g$. What will be the genotypes of her parents? The answer is on page 141.

Biological Terms

Mendelian genetics

Mendelian Genetics
- self-pollinate
- cross-pollinate
- first filial generation
- second filial generation
- unit characteristics, concept of
- dominant and recessive, concept of
- dominant trait
- recessive trait
- segregation, concept of
- phenotype
- genotype
- allele
- homozygous
- heterozygous
- monohybrid cross
- Punnett square
- pedigree
- test cross

Variations of Mendelian Genetics
- incomplete dominance
- locus (plural, loci)
- multiple alleles
- dihybrid cross
- independent assortment, concept of
- multiple gene interaction

Sex Determination and Sex-linked Traits
- autosomes
- sex chromosomes
- sex-linked traits
- carriers

Facets
- fruit fly
- gene linkage
- hemophilia

Review Questions 5B-5

1. Distinguish between autosomes and sex chromosomes.
2. Explain how sex is determined in humans.
3. Why are sex-linked traits passed from father to daughter but not father to son? Can a mother give a sex-linked trait to her son and to her daughter?

Facet 5B-2: The Royal Disease—Hemophilia, pages 138-39

1. What are the characteristics of hemophilia?
2. What is a sex-linked characteristic, and how can you be sure hemophilia is one?
3. Why were no hemophiliac females born until relatively recently?

Thought Questions

1. Why are the garden pea and the fruit fly good organisms on which to study genetics? Why is the human a poor organism on which to study genetics?
2. Distinguish between a dihybrid cross and a cross involving multiple alleles.
3. In what way is incomplete dominance an exception to the concept of dominance? Could multiple alleles be an exception to the concept of dominance? Why?
4. Explain how multiple gene interaction may have confused early researchers who expected traits to be inherited by simple dominant and recessive monohybrid mechanisms.

Answers–Review Questions 5B-5

1. Autosomes are non-sex-determining and are traditionally numbered; sex chromosomes determine the sex of organisms and in humans are usually designated X and Y.
2. A pair of X chromosomes results in a female; an X and a Y result in a male.
3. The sex-linked traits are produced by certain genes on the X chromosome. Since the father passes an X chromosome only to a daughter, these traits can appear only in daughters. A mother can pass on a sex-linked trait (on X chromosomes from her father) to both a son and daughter because her X chromosomes are passed to each.

Answers–Facet 5B-2

1. When cut or hurt, the person bleeds freely because his blood lacks a chemical necessary for clotting.
2. A sex-linked characteristic is one that has its gene on the X chromosome but is not found on the Y chromosome. Sex-linked genes are thus passed by mothers. If the hemophilia trait is given to a son, he will be a hemophiliac. If it is given to a daughter and the father is normal, the daughter will be a carrier. If the mother gives the gene to a daughter and the father is a hemophiliac, the daughter will be a hemophiliac.
3. Since male hemophiliacs usually died before maturity and marriage, until a treatment was developed, there could be no female hemophiliacs. To have a female hemophiliac, a male hemophiliac must marry a carrier. Each daughter then has a 50% chance of being a hemophiliac.

Answers–Thought Questions

1. The garden pea is an ideal organism because the various phenotypes are distinct and are determined by genes on

Answers to Basic Genetic Problems

Free or Attached Earlobe, pages 128-29

Ff × Ff

	F	f
F	F F	F f
f	F f	f f

Genotypes of Guinea Pigs, page 130

1 Bb	5 B–	9 Bb	13 bb
2 Bb	6 B–	10 bb	14 bb
3 bb	7 B–	11 bb	15 bb
4 Bb	8 bb	12 Bb	16 Bb

Corn Kernel Color, page 131

	P	p
p	Pp	pp
p	Pp	pp

Pp × pp

ratios:
genotypic 2Pp:2pp
phenotypic 2 purple:2 yellow

Multiple Alleles Blood Typing, page 133

	I^A	i	
I^B	I^AI^B	I^Bi	Barbara
i	I^Ai	ii	

The Pearsons

$I^Ai \times I^Bi$

	I^A	i	
I^A	I^AI^A	I^Ai	
i	I^Ai	ii	Sally

The Browns

$I^Ai \times I^Ai$

Since Sally is blood type O, she could be the Pearsons' child. If both Pearson parents were heterozygous (Mr. Pearson I^Bi and Mrs. Pearson I^Ai), it is quite possible for them to have a homozygous recessive *(ii)* child who would have blood type O. (See Pearsons' Punnett square above.)

Barbara (type B), however, could not be the Browns' child. Neither Mr. Brown nor Mrs. Brown has the *B* allele; therefore, they could not give it to their daughter. The Browns' children must be either blood type A or blood type O. (See Browns' Punnett square above.) Since the Pearsons could have a child with blood type B, Barbara must be their daughter, and Sally the Browns' daughter.

How can we be sure that the parents' genotypes are the ones used above? Their phenotypes and their daughters' phenotypes can be used to show that there are no other possible genotypes for any of the parents, except Mr. Pearson. He could be heterozygous B *(I^Bi)* or homozygous B *(I^BI^B)* and still be Barbara's father.

Dihybrid Cross of Peas, page 134

GGii × ggii

	gi
Gi	Ggii

Ggii × ggii

	gi	gi
Gi	Ggii	Ggii
gi	ggii	ggii

Recall that a test cross mates an unknown genotype with a known genotype (the homozygous recessive) which in this case is *ggii*. The test cross of a pea that is homozygous for green and constricted pods *(GGii × ggii)* will produce all green-constricted individuals in the F_1. If this happens, the farmer will know that his parent pea is homozygous for those traits. If a heterozygous green pea is test crossed *(Ggii × ggii)*, 1/2 the offspring will be yellow constricted. If this happens, the farmer knows that his parent pea was heterozygous for pod color.

Red-green Colorblind Female, page 140

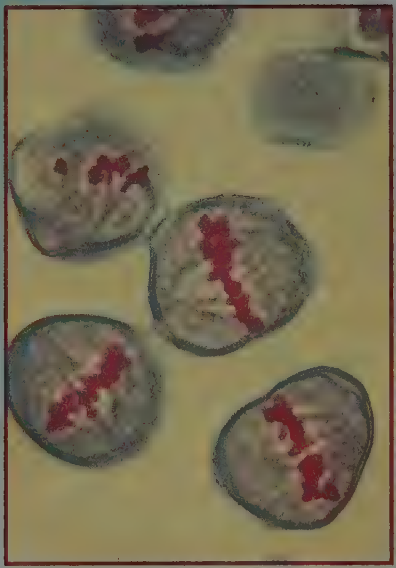
A red-green colorblind girl *(X^gX^g)* can be born to a red-green colorblind man *(X^gY)* and a carrier woman *(X^GX^g)*. The father must be red-green colorblind, because if he has normal vision he can give only normal genes for this trait to his daughter. If she gets a normal gene, she will not be red-green colorblind. The mother must be a carrier *(X^GX^g)* in order to be able to give the recessive trait to her daughter.

Visual 5B-11 involves a pedigree that advanced students will find a challenge. It is not terribly difficult, but it does involve problem-solving skills. It should be used only after students are familiar with working sex-linked pedigree problems (like the hemophilia problems in the Laboratory Manual). Consider doing the problem in class, merely showing students how it is done. Charts showing various attempts to work out the pedigree with different traits are given on page T35.

separate chromosomes. The fruit fly has a short life cycle, which allows many crosses to be made in a short time. Also, the phenotypes are easy to distinguish. Genetic studies on humans are cumbersome because man cannot and should not conduct controlled experiments on inherited human characteristics. Not only are the ethical problems insurmountable, but the life span is so long that observing the results of successive crosses requires long periods of time.

2. A dihybrid cross involves the interaction of two different gene pairs at different loci; multiple alleles are two gene pairs of several alleles at one locus.
3. Incomplete dominance is actually codominance, or it could be interpreted as a lack of dominance, because no specific trait is truly dominant over the other traits. Multiple alleles also differ from incomplete dominance but may exhibit incomplete dominance as in the ABO blood groups, in which no specific blood antigen is dominant.
4. Early researchers knew of only the simple dominant and recessive mechanisms and would not have explained the results of multiple gene interaction by the mechanism with which they were familiar. The phenotypes produced by multiple gene interaction would have been unexpected and confusing.

mutation: (L. MUTARE, to change)



ADVANCED GENETICS
THE CONTINUITY OF LIFE PART II

SIX

Time Frame
6A with Facet: 1-2 periods
6B with Facet: 1-2 periods

Laboratory Activity
6–*Genetic Research* involves finding articles regarding current genetic research. The project can be done outside of class, or it can be used for class discussion.

Mutation has many different meanings and is therefore often confusing. For simplicity and clarity, this text employs a restricted usage of the term.

6A–Chromosome and Gene Changes

The inheritance mechanisms discussed thus far could be considered normal. In most cellular divisions, gamete formations, and gamete combinations (fertilizations), the principles of Mendelian genetics hold true. There are, however, many irregularities that can occur. Some of these are merely a reshuffling of genes and happen quite regularly in most organisms without any noticeable effects. Other irregularities are **lethal**, killing the organism or causing abnormal (weak or deformed) organisms.

There are 2 basic types of genetic changes:

- **Chromosomal changes** which involve either the *number of chromosomes* or the *arrangement of genes on a chromosome*, and
- **Gene mutations*** (point of mutations) which change the sequence of bases in a gene.

6–The Continuity of Life Part II: Advanced Genetics

This is the dawning of the Genetic Age. Computers are wonderful and powerful tools, and nuclear energy may be the most powerful physical force known to man, but these are outside forces. Computers and nuclear bombs and power plants are devices that may be used or abused as man chooses. The Genetic Age, although it approaches slowly (compared to a nuclear bomb or the need to computerize to remain competitive), is as sure as the power locked in atoms and as present as silicon chips.

Just because the Genetic Age approaches almost imperceptibly does not mean it lacks power or is any less a threat to the current way of life than the Atomic or the Computer Ages. The gene, which is the foundational unit of all living things, has been until now a relatively unalterable unit. Even the groupings of genes (chromosomes and genomes) were beyond man's power to deal with. Any tampering with genes, chromosomes, or genomes was crude and usually resulted in abnormalities. Current technology, however, makes genes, chromosomes, and genomes alterable. Now the foundation of physical life can be redesigned, causing changes in living things which will make nuclear power and destruction seem insignificant and put the mightiest computer in its place as a mere "tool of man."

Anyone who does not recognize the significance of the dawning Genetic Age is uninformed. There will probably never be a major explosion that will make his ignorance obvious. Those who have seen the "DNA dawn" must make others aware of what is happening.

This awareness of the changes in the realm of genetics is especially important for Christians. The tampering with physical life

Changes Affecting the Numbers of Chromosomes

The **genome** (JEE NOME) of an organism is 1 single complete set of its chromosomes. A normal haploid gamete contains a complete genome. A diploid organism has cells with 2 complete genomes. Most organisms with which you are familiar are diploid in their adult stage. Diploid organisms must carry on meiosis in order to form haploid gametes. At fertilization, the haploid gametes combine to produce a diploid zygote.

There are, however, some organisms that are haploid even as adults, forming gametes without going through meiosis. Mosses, algae, and many fungi, for example, are haploid. Their diploid zygote, however, usually undergoes meiotic divisions before the organism begins to grow.

In the insect world there are other naturally occurring haploid organisms. The queen and worker bees are diploid, but the drones (males) are haploid, developing from unfertilized eggs. Scientists call the development of an unfertilized egg **parthenogenesis*** (PAR thuh noh JEN ih sis).

Euploidy

Euploidy (YOO PLOY dee) involves the addition or loss of an entire genome. For example, some diploid organisms can be made to produce haploid offspring by artificial parthenogenesis. Unfertilized eggs from many amphibians (frogs and salamanders) can be treated in the laboratory and forced to develop. The resulting haploid organism is smaller and weaker than the diploid organism as well as sterile. Thus far the turkey is the largest animal that has been induced to develop by parthenogenesis. Haploid turkeys are smaller than normal and do not have quite enough feathers.

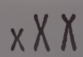
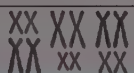
Any cell or organism that has 3 or more genomes is a **polyploid.** Polyploids are of 2 basic types: those that have multiples of the same genome and those that have multiples of different genomes.

Triploids

If a diploid gamete is fertilized by a haploid gamete, the resulting zygote is **triploid** (3n), having 3 genomes. During mitosis all the chromosomes replicate and divide normally. When a triploid organism enters meiosis, however, and the chro-

parthenogenesis: partheno- (Gk. PARTHENON, virgin) + -genesis (beginning)

Various Chromosome Number Changes 6A-1

euploidy (complete genomes)	**haploid (n)** a single genome		gametes, moss, algae, fungi, drones
	diploid (2n) multiple of same genome		most plants and animals, man
	triploid (3n) multiple of same genome		seedless watermelons, bananas, some plants
	tetraploid (4n) multiple of same genome		Irish potato, alfalfa, some rare plants
	tetraploid (2n + 2n) multiple of different genomes		corn, wheat
aneuploidy (incomplete genomes)	**monosomy (2n – 1)**		various types of plants, Turner's syndrome in humans
	trisomy (2n + 1)		various types of plants, mongolism and Klinefelter's syndrome in humans

Consider using this chart to present and summarize the material on the next few pages.

Visual 6A-1 can be used as a visual outline for a discussion of the material on this and the next few pages.

is not to be taken lightly. Christians are to be good stewards of what God has given them and thus must be careful about what genetic engineers are permitted to do with the environment. (This topic is discussed with related Scriptural principles in Chapter 18.) A more significant concern for Christians is eugenics, the application of Genetic Age technology to the human gene pool and individual genomes. Work with human genetic material is being done, and more will be done as technology increases. Christians will be ignorant of advances and how to respond to them if they do not become informed and apply Scriptural principles to these issues.

It is impossible for anyone to foresee answers to many future genetic problems–one cannot even be sure what the exact questions will be. The principles of Scripture, however, are steadfast and sure. Since man does not yet know when "high noon" of the Genetic Age will be, no one can supply the answers which will be needed at that time. Christian educators shirk their responsibility to their students if they ignore the scientific background needed to understand the problems or do not present the Scriptural principles which will apply to the problem. Teachers have an obligation to their students not to prepare them to deal with all situations but to expose them to the information they may need in order to deal with problems they will face. Then, having done their part, teachers should pray for the Holy Spirit to do His work.

Unlike Chapter 5, this chapter contains little that students need to master by drill and practice. Most of the material in this chapter should be presented as a survey of what exists, using some class discussion in the later sections of Chapter 6B.

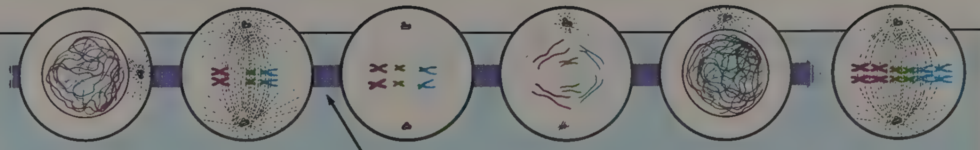
This box contains supplemental material that can easily be omitted. The term **colchicine** is listed in the Biological Terms section at the end of the chapter and is used throughout the opening section of this chapter. Be sure to inform students if they are expected to know this term for testing purposes.

How colchicine works is not as important as the fact that it makes the chromosomes double without cell division.

For some animals to develop as haploids requires only that their ovum be pricked by a hair; thus the large ova of amphibians and birds are prime candidates for experimentation. The technique does not appear to work on all birds or on any mammals.

Polyploidy in animals is extremely rare.

Although there are a few well-known natural tetraploids, most of today's triploids and tetraploids result from human intervention and are kept alive only by cultivation.



The chromosome number is doubled by prohibiting the segregation of chromosomes during cell division.

Forming Polyploids

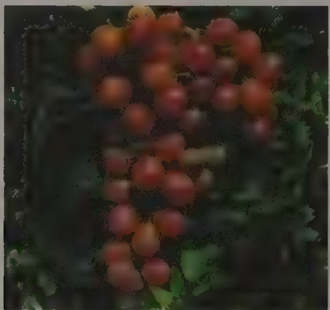
Some polyploid organisms exist naturally and some can be induced artificially. To induce polyploids in the laboratory, scientists often use **colchicine** (KOHL chih SEEN), a poisonous drug extracted from the autumn crocus plant. Colchicine dissolves the spindle fibers of dividing cells. Without spindle fibers the chromosomes do not divide and migrate into the daughter cells.

Since the chromosomes have not separated, the cells will have doubled their chromosome number when the drug wears off. Colchicine, then, applied to cells entering meiosis, causes the production of *diploid gametes.*

mosomes line up, the third homologue prevents successful replication and unfertile (or sterile) gametes are produced.

Living triploids do not occur in the animal kingdom (nor in humans), but they occasionally appear in other kingdoms. Triploid plants are usually taller and stronger, have more and larger leaves, and produce larger fruits than their diploid counterparts. Some triploids are therefore cultivated as ornamental plants.

Triploid grapes, oranges, and other fruits are common on today's market shelves. Because they lack seeds, triploids must be reproduced asexually. A triploid seedless watermelon can be produced with the use of colchicine. Since watermelon vines and other annual plants live only 1 year, however, obtaining seedless fruits from annual plants is expensive.



6A-2 *Triploid grapes are larger than their diploid counterparts.*

Tetraploid

Tetraploid (TET ruh PLOYD) organisms (having 4 sets of chromosomes) are common in plants but rare in animals. Some cells of the human liver are tetraploid. For some reason, and by an unknown mechanism, some human liver cells completely duplicate their chromosomes without dividing. These cells, then, have 4 genomes (abbreviated 4n). Since liver cells do not form gametes, this unusual chromosome number does not affect the offspring. Other than in liver cells, tetraploidy is unknown in humans.

6A-3

The white potato: 4n = 48.

The white or Irish potato is a tetraploid. The genome of a potato has 12 chromosomes (n = 12), and the diploid state is 24 chromosomes (2n = 24). The cells of an Irish potato, however, have 48 chromosomes (4n = 48). The 4 homologues lining up together result in problems during meiosis, and few fertile gametes are formed. Instead, farmers use the eyes of the potato to reproduce this crop asexually.

6A–Chromosome and Gene Changes

Objectives–Chapter 6A

- ❑ Describe several types of chromosomal changes and give examples of each.
- ❑ List several useful polyploid conditions and examples from the plant kingdom. Account for the lack of polyploid organisms among the animals.
- ❑ Recognize crossing over and translocation as a means of shuffling genes.
- ❑ Describe a gene mutation and tell why gene mutations are usually genetically insignificant when somatic but potentially significant when occurring in germ cells.
- ❑ Explain why gene mutations are harmful to a gene.
- ❑ Define and give examples of *gene action* (a gene being turned off and on).
- *❑ Explain why genetic disorders, at present, cannot be cured but often can be treated. List several examples of human disorders that can be treated and some that cannot be treated.

*From a Facet.

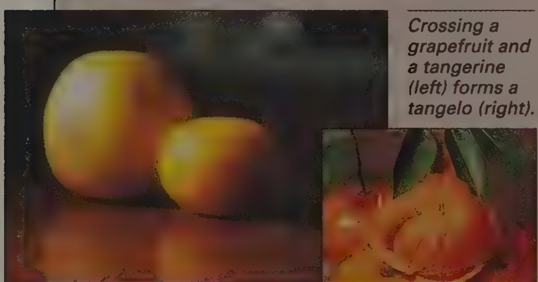
Man's Use of Polyploids

Man has often looked at the plants and animals he grows for food and wished that one organism could have the desirable traits of two. The Russian plant geneticist, Karpechenko, is remembered for his desire to have a plant that produced the large edible leaves of a cabbage and the large edible root of a radish. In 1927 he crossed a radish (2n = 18, genus *Raphanus*) with a cabbage (2n = 18, genus *Brassica*) and eagerly awaited the results. He even invented the word *Raphanobrassica* as the scientific name for this new plant.

Some seeds were formed, but the plants that grew were sterile. Since the chromosomes were from 2 different genomes, the 9 radish chromosomes did not pair with the 9 cabbage chromosomes during meiosis. This plant had the diploid chromosome number (2n = 18), but its genetic make-up was really 2 haploid genomes (n + n = 18).

In a few plants, however, the chromosomes doubled, forming a tetraploid (2n + 2n = 36). These plants were fertile, each of the chromosomes having a partner during meiosis and producing seeds that grew new plants. *Raphanobrassica* was hailed as a new, man-made species. Although it cannot grow in the wild, it can be cultivated. Today you can buy *Raphanobrassica* seeds, but the plant is not grown for food. To Karpechenko's dismay, it has radish leaves and cabbage roots.

Most of man's attempts to cross organisms from different genetic backgrounds have met with a similar lack of success. Occasionally some crosses between similar species do produce valuable offspring. A cross between a grapefruit and a tangerine results in tangelos. Once a plant with desirable traits is obtained, asexual reproduction is used to keep the organism's line alive.



Crossing a grapefruit and a tangerine (left) forms a tangelo (right).

Many of our most valuable crops are polyploids: corn, wheat, cotton, grapes, alfalfa, bananas, potatoes. Humans had nothing to do with developing these polyploids: They are believed to have happened spontaneously. These plants, however, would also have spontaneously ended were it not for man's cultivation of them. Many polyploids, like grapes and bananas, are either sterile or produce seeds that carry inferior characteristics. Although wild counterparts of these plants exist in nature, the polyploid strains require man's cultivation. Even many fertile polyploids, like corn, wheat, and cotton would become extinct within a few years if man did not cultivate them.

The wild grasses are believed to be ancestors of the cultivated wheats.

Man has been greatly involved with the genetics of these cultivatable plant polyploids since they were formed. These plants have been crossed and recrossed, forming many different strains. It appears that their extra chromosomes have permitted a greater flexibility among the expression of their genes. Consequently, many polyploid crops can grow in different areas and produce variations of their products. Consider all the different kinds of corn, wheat, and potatoes.

Some Christians have speculated that God permits these genetic conditions for the benefit of man but does not permit similar genetic variations on a widespread basis. Although various polyploids have apparently formed naturally, polyploidy does not happen often. Man has not actually observed the forming of polyploids except when drugs (such as colchicine) or other experimental techniques are used. Most polyploids induced by man are like *Raphanobrassica*, of little value when compared with the ones that are believed to have happened naturally.

See additional information in the Facet dealing with clones (pp. 118-20) and in the plant reproduction section (pp. 328-30).

It could be that God caused such polyploids as corn, wheat, or cotton in the past as man needed them, and that in the future when there is a need, God may permit other polyploids to develop, either spontaneously or through human intervention. To date, however, most attempts have been similar to *Raphanobrassica*.

It is possible that scientists will develop some new plant polyploids that will help to feed the world, grow in areas where profitable crops cannot currently be grown, or produce more edible or nutritious foods. Some have speculated that this kind of "miracle" will help to establish the antichrist as "god" (Rev. 13). Some have speculated that Christ will use this kind of advancement to feed the great population expected during the Millenium. All of this is interesting speculation, but it is without direct Scriptural or scientific backing.

Notes–Chapter 6A

An understanding of Mendel's genetics, although basic to an understanding of what is happening in genetics today, does not begin to touch what has been done in the genetic realm. This chapter is a survey of some of the most important areas beyond Mendelian genetics that have been studied and are useful in agriculture or in explaining human disorders.

Careful study of the material in this chapter is typically done in college genetics courses, not high school survey courses. That does not mean that only those who go on in science should be exposed to it. Most people who consider the content will agree that most students are interested in and should be exposed to this material.

Much of the "evidence" for evolution which is often cited to "impress" a person can actually be attributed to the normal, and very limited, processes presented in this chapter. To understand, for example, that mutations do not cause evolution, one must understand what a mutation is and is not.

The basic material of this chapter deals with how genes and chromosomes change, have changed, and can be changed. The material, on the level presented here, is not too difficult for the normal high school student. Mastery of every point in the chapter is not a good or even meaningful goal. Teach this material for general understanding (survey), not for the details.

Facet–Chapter 6A

The Facet in this chapter covers several interesting genetic disorders. Each disorder can be covered in class in a few minutes. It is recommended that students read the Facet even if it is not discussed in class.

Summarize this box in class if time is limited.

The children of Israel were not to produce mules, because mules were unclean animals (see information about horses and donkeys, p. 448).

The Mule

The mule is a well-known exception to many of the genetic "rules." A mule is a cross between a female horse and a male donkey. The horse has 64 chromosomes per body cell nucleus, and the donkey has 62. The union of a horse gamete (n = 32) and a donkey gamete (n = 31) results in a mule with 63 chromosomes (n + n = 63). Because the horse chromosomes and the donkey chromosomes are different, they fail to pair properly during meiosis. At the same time, the mule's uneven chromosome number forces 1 chromosome to be without a pairing partner. This presumably causes sterility.

Someone has rightly said that a mule is an animal with an ignoble past and a hopeless future; however, 1 in 10,000 female mules can conceive and bear young. It seems that for some reason the gametes she forms have either all the horse or all the donkey chromosomes. Depending upon the kind of male being bred, the offspring of a female mule are usually horses or donkeys, rarely mules. No fertile male mules have been known to exist.

The mule is a cross between a horse and a donkey, but it is a genetic dead end.

The mule, with its unusual characteristics, was the ideal animal to meet many of man's needs before the invention of cars, trucks, and certain types of machinery. Today man breeds very few mules.

American upland cotton is a tetraploid of 2 different genomes. The cells of this cotton plant have 52 chromosomes divided into 2 sizes, 13 large pairs and 13 small pairs. The large are called *A*, and the small are called *D* chromosomes. The large *A* chromosomes resemble the chromosomes of a smaller Asiatic cotton from India. The small *D* chromosomes resemble the chromosomes of a wild American plant.

If the Asiatic cotton plant is crossed with the wild American plant, a hybrid offspring with 26 chromosomes (13 *A* and 13 *D*) results, but it is sterile. If the sterile hybrids are treated with colchicine, the chromosome number doubles. These treated plants produce fertile flowers and seeds. The seeds produce plants with 52 (2n + 2n) very similar to upland cotton. This evidence does not prove that upland cotton comes from these other 2 plants, but it does support the theory.

6A-4 *Cultivated cotton is a complex tetraploid.*

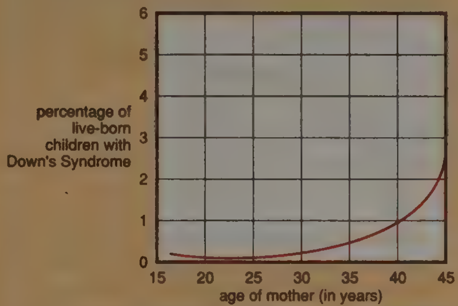
Aneuploids

Aneuploids (AN yoo PLOYDZ), some of which lack or have extra chromosomes, do not have complete genomes. Most aneuploids are believed to be the result of an error during meiosis. For some unknown reason, occasionally a chromosome pair fails to separate during meiosis. This is called **nondisjunction.** Two of the resulting gametes therefore have an extra chromosome (n + 1), and 2 lack a chromosome (n − 1).

If the gamete that has an extra chromosome unites with a normal gamete, the result is a *trisomy* (try SO mee) of 1 of the chromosomes (2n + 1). All the chromosomes are in the diploid state, except 1, which has 3 chromosomes instead of 2.

Aneuploidy in Humans

The genetic make-up of humans (as well as animals) appears to be quite fixed when compared to plants, meaning that many of the chromosome changes which are common in plants do not happen in humans or animals. In humans, however, there are a couple of well-known aneuploid conditions.



In humans, **Down's syndrome (mongoloidism)** is caused by a trisomy of the twenty-first chromosome. Those with Down's syndrome may be male or female and are characterized by low mentality, shortness, stubby hands and feet, an extra fold of skin on the eyelids (hence the name *mongoloid),* and often other defects. At one time people believed that having a Down's syndrome child meant there was an oriental in the family's ancestry. This is not true. One out of every 600 people born in the United States has Down's syndrome.

Occasionally someone is born with a trisomic condition of one of the other smaller human chromosomes. In these cases, however, the individual is deformed, and his life expectancy is only a few weeks.

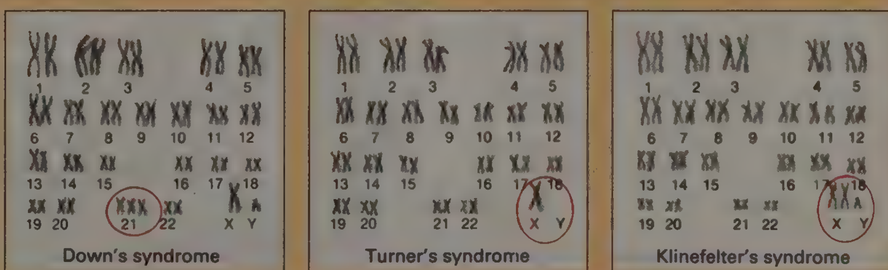
Some Down's syndrome people suffer more mental retardation than others. In the past they were all assumed to have a very low intelligence. Proper training helps them develop to their full potential.

Various aneuploids of the sex chromosomes also occur. Possible conditions are these:

- *Turner's syndrome (XO)* Females lack a second sex chromosome resulting in underdevelopment of the female sex glands, shortness, and other deformities.
- *Klinefelter's syndrome (XXY)* This male often appears normal but is infertile.
- *Trisomy X (XXX)* Various symptoms may develop in these individuals. Many appear normal, but some resemble women with Turner's syndrome, and some are so-called "super females," having a tendency toward male characteristics. Many of these individuals are sterile.

Aneuploids of other human chromosomes have been found in naturally aborted fetuses. Aneuploid conditions of most human chromosomes are therefore believed to be lethal before birth. Only the sex chromosomes (which are believed to carry relatively few genes) and a couple of the autosomes can be trisomic or monosomic and not kill the individual. Almost all human aneuploids that survive birth are sterile, or they die before they reach maturity. Human and animal aneuploids generally do not propagate.

Karyotypes of genetic disorders



This box contains supplemental material which should be studied by most students. Omit this box if time is limited. The box presents that human aneuploidy, although it exists, is rare and always deleterious (that the human genome is so "tight" that only minor changes can pass through the genetic screen).

The term **Down's syndrome (mongoloidism)** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

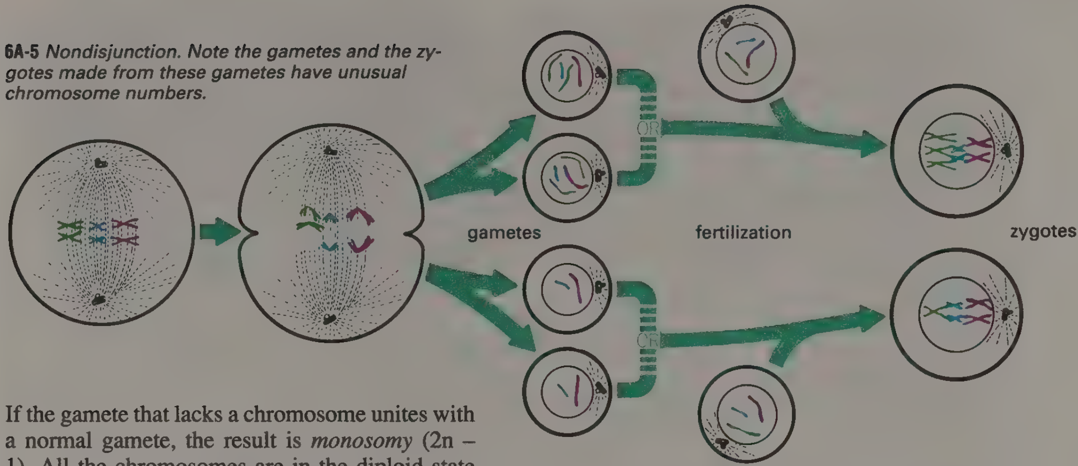
Many in the class will know of someone who has Down's syndrome. Take care not to demean those who are deformed (see the discussion of human genetic abnormalities, pp. 154-55). Make the students aware that Down's syndrome does not result from something the parents have done. Monosomic and trisomic conditions of human chromosomes in gametes are thought to be common. People with Down's syndrome are some of the few that survive until birth. A woman over the age of 40 who is having a child appears to be more likely to have a Down's syndrome child.

Other sex-chromosome abnormalities result from nondisjunction. They are even more rare than the examples given. It generally appears that the more abnormal the chromosome number is *(XXXY, XXXX),* the more impaired the person is.

At one time *XYY* men were thought to be violent and prone to be criminals. The condition was first studied in prison inmates and appeared to be in a higher percentage of criminals than in the general population. Further testing found this assumption to be in error. *XYY* men are generally normal. This would be expected, considering how few genes can be traced to the *Y* chromosome.

Students may find it interesting to look up and find out about these other trisomic conditions. Trisomy 18 is also known as Edward's syndrome, and Trisomy 13 is called Patau's syndrome.

Go over this diagram carefully, noting especially the green chromosomes.



6A-5 *Nondisjunction. Note the gametes and the zygotes made from these gametes have unusual chromosome numbers.*

If the gamete that lacks a chromosome unites with a normal gamete, the result is *monosomy* (2n – 1). All the chromosomes are in the diploid state except for one, which is single. Other numbers of missing or additional chromosomes do exist but are rare.

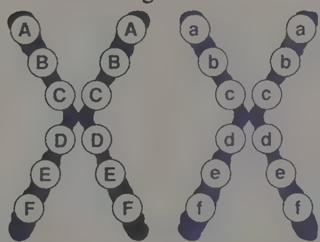
Aneuploids are common in the plant kingdom, especially in cultivated crops. Some of the various types of wheat, for example, are aneuploids of a complex polyploid. Aneuploids in the animal kingdom and among humans are known to exist, but the trisomy or monosomy condition can only happen with a few of the chromosomes. It seems that having too few or too many genes is usually lethal in animals and humans.

Review Questions 6A-1

1. Name the 2 major types of genetic changes, and briefly describe each.
2. How has colchicine been used to aid our understanding of polyploid conditions?
3. Why are most tetraploid organisms fertile when triploid organisms are sterile?
4. Distinguish between euploid and aneuploid organisms.
5. Describe how nondisjunction can cause aneuploid organisms.
6. Describe the genetic condition that results in Down's syndrome (mongoloidism).
7. In what ways are polyploid plants advantageous to humans?
8. It has been said that although many polyploid plants appear strong, as a species they are weak. What basis could be used to support this statement?

Changes Within the Chromosome

Thus far we have discussed changes in the numbers of chromosomes, but there can also be changes within the chromosomes themselves. Chromosomes are actually long chains of many genes. This form, called **gene linkage,** can be visualized as a string of pearls. It is possible for a string of pearls to break and be repaired. Such breakage happens quite often in chromosomes. There are, however, some unusual results if the "gene-pearls" are strung together in a different sequence or end up on a completely different strand altogether.



6A-6 *Gene linkage on a homologous pair of chromosomes. All the genes on one homologue are dominant and all on the other are recessive.*

Answers–Review Questions 6A-1

1. (1) Chromosomal change–change in chromosome number or the sequence or number of genes on a chromosome; (2) gene mutation–the gene itself is changed
*2. Colchicine dissolves spindle fibers of dividing cells and inhibits division and migration of chromosomes. This produces diploid gametes and is used to induce polyploids for study.
3. During meiosis of triploid organisms, the third homologue interferes with the lining up of chromosomes and causes production of infertile gametes. Tetraploid organisms, however, have complete pairs of chromosomes which usually line up and separate normally.
4. Euploidy involves the addition or loss of an entire genome; aneuploidy involves lacking or having extra chromosomes, but not complete genomes.
5. In nondisjunction, a chromosome pair fails to separate during meiosis. Two of the gametes then have an extra chromosome, and two lack a chromosome. When they unite with normal gametes, trisomy and monosomy (respectively) result.
*6. Down's syndrome usually occurs because of a nondisjunction of the twenty-first chromosome, resulting in a trisomy of the twenty-first chromosome.
7. Many polyploid plants are larger and stronger than their diploid counterparts. Some of them are sterile, producing no seeds, which is advantageous in some organisms (bananas, grapes).
8. The plants may be healthy and strong, but most polyploids (both natural and man-induced) require cultivation to continue growing year after year. As a species they would not exist in the wild, which can be considered a weakness.

*From a box.

Exchange of genes between homologues

If, during the first metaphase of meiosis when the homologues line up, the 4 sister chromatids break and the pieces join with their own respective ends, nothing noticeable happens. If, however, the sister chromatids break and the pieces join with the ends of the other chromatids, **crossing over** occurs.

Suppose that dominant genes *ABCDEF* are linked in that sequence on one chromosome. When this chromosome has replicated to form sister chromatids, it is illustrated as follows:

ABCDEF
ABCDEF

A gamete of this individual is shown as follows:

ABCDEF

A homologue having all the recessive genes would be illustrated like this:

abcdef
abcdef

In this example, you would always expect an individual who has the dominant characteristic *A* also to have the dominant characteristic *F* because the genes are together on the chromosome. Even a heterozygous individual has the dominant characteristics for *A* and *F*.

heterozygous individual		gametes
ABCDEF		ABCDEF
ABCDEF	→	ABCDEF
abcdef		abcdef
abcdef		abcdef

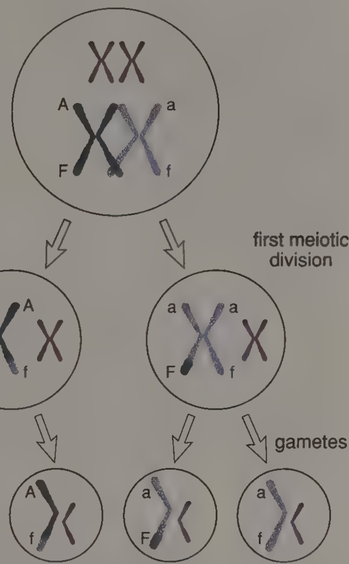
If crossing over occurs in a heterozygous individual, it may form a gamete containing both *A* and *f*.

meiosis lineup		crossing over		gametes
ABCDEF		ABCDEF	→	ABCDEF
ABCDEF	→	ABCdef		ABCdef
abcdef		abcDEF	→	abcDEF
abcdef		abcdef		abcdef

If this gamete combines with a normal recessive gamete, it will produce an individual who has the dominant characteristic for *A* but the recessive characteristic for *f*.

ABCdef
abcdef → ABCdef / abcdef

Crossing over, although occurring regularly and at a predictable rate for a given set of genes, is not frequent enough to cause the ratios of genes on the same chromosome to be the same as genes that are on different chromosomes. Different rates of crossing over for different sets of genes have enabled geneticists to map genes (determine their sequence) on a chromosome.



6A-7 *Crossing over often results in unexpected combination of genes.*

Crossing over sometimes happens two or more times within a single chromosome pair. If the chromosomes join together so that there is a complete set of genes in each chromosome, there are no bad effects. This crossing over merely shuffles the genes that are linked on the chromosome and thus permits greater genetic variation.

Exchange of genes between nonhomologues

Occasionally, two nonhomologous chromosomes cross over during meiosis. This crossing over is

Crossing over is a single concept with complex consequences. The concept that genes linked on a chromosome do not segregate independently is not essential for all students to master. It is suggested that *crossing over* be presented quickly for the brighter students and the concept summarized for the average student. Do not spend a long time in a general survey course on this topic. In advanced classes, consider developing the concept with additional materials.

translocation: trans- (across) + -location (LOCARE, to place)

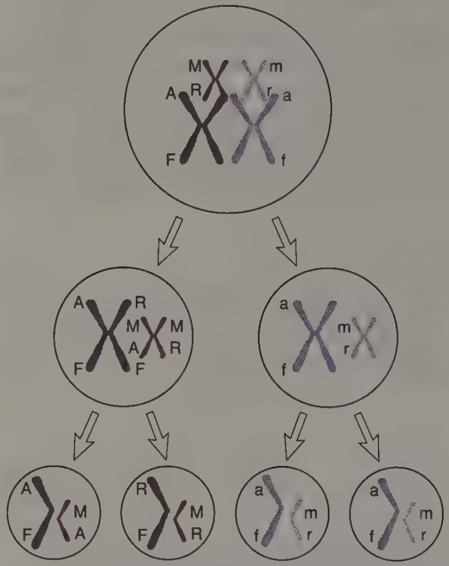
Myeloid leukemia may be caused by an extra piece of one of the human chromosomes on another chromosome.

In some cells very large chromosomes can be found. These large chromosomes are actually many replications of the same chromosome held together. On these large chromosomes the genes that are active appear as puffs (often called *chromosome puffs*), and those that are not active are tightly coiled and appear as dark bands. In the salivary glands of the fruit fly, this type of chromosome is easily observed. If the salivary gland is treated with chemicals, the puffs appear in different places. Some of the functioning genes shut down, and some of the formerly inactive genes turn on.

Visual 6A-2 can be used as visual representation of crossing over and translocation.

Scientists are working on being able to take some of an individual's cells and then, by turning genes on and off, to grow a new organ (or tissues which comprise an organ) and to use it to replace a damaged organ. The problems of rejection and the need to suppress the immune system would be eliminated. The liver, with its relatively unstructured nature, may be among the first "homotransplants."

called a **translocation.*** Some gametes made from cells that experienced translocation will be normal, but some will have extra genes, and some will lack certain genes.



6A-8 *Translocation results in some gametes with extra genes and some gametes with missing genes.*

About 4% of the people suffering from Down's syndrome have a translocation of genes from the twenty-first chromosome onto one of their other chromosomes. This translocation causes the zygote to have 3 sets of the genes on the translocated segment of its twenty-first chromosome. A person with this condition will have Down's syndrome even though he has only one pair of chromosome twenty-one. The 3 sets of *genes* cause the syndrome.

Occasionally a segment of the chromosome is left out after crossing over. This is a *deletion.* For example, for every mongoloid formed by translocation, there should also be gametes formed that have a twenty-first chromosome with *missing* genes. In humans the resulting condition is presumed to be lethal because such individuals have not been found.

Sometimes the deleted segment of a chromosome does not join a chromosome and therefore does not migrate during meiosis. The chromosome piece usually winds up outside the nucleus, where it disintegrates. If this happens, the cell lacks genes. A person with such a lack may suffer very harmful effects. *Cri du chat* (cry of the cat) results from the deletion of part of the fifth chromosome. When a baby has this deformity, its cry sounds like a cat's screeching.

Review Questions 6A-2

1. How could crossing over affect gene linkage?
2. What 2 human conditions are believed to result from translocation?

Gene Action and Gene Mutations

Thus far we have spoken of genes as the basic unit of inheritance. Genes, however, are not unalterable units. They may be turned off (that is, they may become inactive, no longer making their protein) and turned on (that is, they may become active, causing their protein to be made). Genes can also be altered to stop functioning or to stop producing protein.

Gene action

Not all the approximately 100,000 genes you have in every nucleus are functioning in all your cells. For example, many of the genes for eye color are not functioning in most of your body's cells. *Cell specialization* in the cells of an embryo is caused by turning on some genes and turning off others. By mechanisms we do not completely understand, certain genes that are activated in some cells cause those cells to become nerve tissue; other genes activated in other cells cause those cells to become muscle tissue, and so forth. The fact that cells on your head, and nowhere else, developed into your eyes is one of the mysteries of your body, for it is "fearfully and wonderfully made" (Ps. 139:14).

Answers–Review Questions 6A-2

1. **(1)** Extra genes; **(2)** missing genes (deletion)
2. **(1)** Down's syndrome; **(2)** *cri du chat*

Scientists are working to discover the mechanism for cell specialization in embryos. When successful, they may be able to induce human cells to replace diseased or damaged organs by growing new organs rather than trying to use transplants or artificial devices.

Some factors that control gene action

Some of the genes in your body may function in all your cells. The genes for the manufacture of the enzymes in the citric acid cycle, for example, must be active in all your cells, since all of them are capable of this important cellular process.

Some genes in your cells turn on and off by various mechanisms. A few genes, for example, are affected by the concentration of the proteins they produce. If a cell has an abundant supply of a particular protein, the DNA stops manufacturing the messenger RNA (mRNA) responsible for that protein until the supply reduces.

During the winter the Himalayan rabbit is normally white with black ears, nose, tail, and feet. If, however, the hair on his ears and tail is removed and these body parts are kept in heated mufflers while his winter coat regrows, the fur will regrow white. If an area of the rabbit's back is kept cold while his hair is growing, the hair will be black. In this example, temperature turns on or off the gene for coat color.

6A-9 *An experiment with the Himalayan rabbit demonstrates the effect of temperature on genes.*

Other environmental conditions may cause genes to be turned on or off. The immunities you develop when you are exposed to certain diseases are also the apparent result of turning on and off certain genes. In this case, the factor responsible for turning on the gene is usually either the substance that causes the disease or a product of the disease (see pages 570, 572-76).

Sex-limited characteristics are illustrations of the regulation of genes. The presence or absence of sex hormones turns on or off the genes of sex-limited characteristics. The feathers of the male bird, brightly colored when compared to those of the female of the same species, are a sex-limited characteristic.

6A-10 *The female duck (left) has the genes for the bright colors of the male (right). The expression of these genes, however, is limited by the sex hormones.*

Sex-limited characteristics in humans include growth of body hair, beard growth, breast development, and milk production. Both male and female humans have genes for all these characteristics. The male reproductive hormones stimulate the growth of body hair and beard in young men, while the female hormones stimulate breast development in young women.

Many of the human secondary sex characteristics are sex-linked characteristics (see p. 609).

Since normal people do not produce large quantities of both male and female sex hormones, either the male characteristics alone or the female characteristics alone are stimulated; hence, the characteristics are *limited* to one sex or the other. Occasionally, because of hormonal treatments, cancer, or certain malfunctions of the hormone glands, the sex hormones can become unbalanced; when this happens, a woman may develop a beard and body hair, and a man may develop breasts. Medical treatment can correct these problems.

Be careful to point out the difference between a sex-linked characteristic and a sex-limited characteristic (see pp. 137-40).

Review Questions 6A-3

1. Give an example of the environment's influencing a genetic trait.
2. Since every cell in your body has the same genes, why is every cell in your body not like every other cell?
3. Under normal circumstances the beard genes are not activated in women and the milk-production genes are not activated in men. What mechanism accounts for this?

The same mechanism causes the dark fur on the Siamese cat.

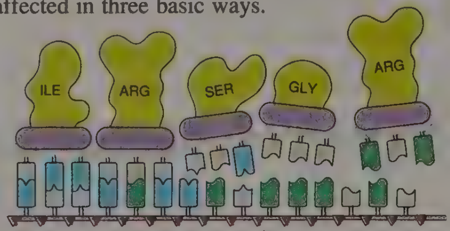
Answers–Review Questions 6A-3

1. The Himalayan rabbit's fur color changes with environmental changes.
2. Certain genes are regulated (turned off or on) by other chemicals and possibly other mechanisms (like temperature). This specific regulation of the genes causes the variation in different cells of the body.
3. These characteristics are sex-limited. They are turned on by the presence of sex hormones. Since men produce abundant male hormones, they grow beards. Certain female hormones stimulate the production of milk.

Ask the students why mutations in tRNA or rRNA would not affect the protein. Neither tRNA nor rRNA contains the code for the sequence of bases, only the "tools" for reading the message. If the tools still work, no odd proteins will be formed. If the tools do not work, no protein is made, and the cell dies.

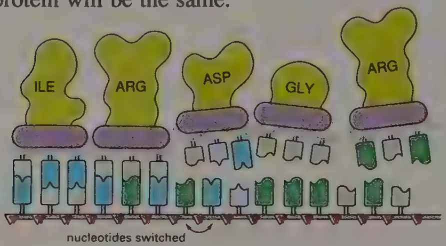
Gene mutations

The term *mutation* often refers to a **gene mutation** (or *point mutation*): the alteration of an individual gene. A gene is a section of DNA that has the genetic code. The DNA code is used to make messenger RNA (mRNA) that directs the manufacture of an amino acid chain of a protein. The codons of RNA (triplets of nucleotide bases), which code for particular amino acids, can be affected in three basic ways.



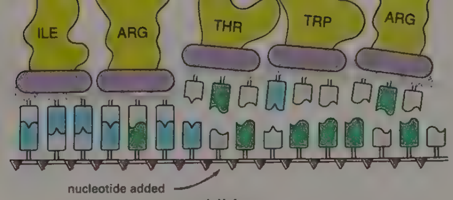
normal

❑ *Substitution* A substitution happens when a nucleotide in the DNA sequence is removed and replaced with a different nucleotide or when 2 nucleotides are inverted. If the substitution makes an RNA codon that codes for the same amino acid (for example GCA and GCC both code for alanine), the mutation will not be noticeable. In the substitution illustrated, however, the new codon calls for a different amino acid, but all of the other amino acids in the polypeptide chain of this protein will be the same.



substitution (inversion)

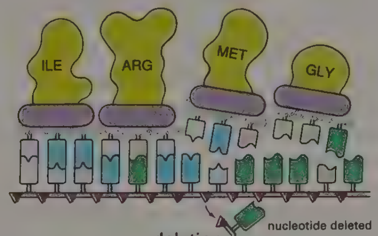
❑ *Addition* In addition an extra nucleotide is placed in the mRNA sequence. With a nucleotide addition a new *reading frame* on the RNA is established. In other words, the codons after this point are off. The chance is minute that they will code for a polypeptide chain of amino acids that is at all similar to the original. The exact location



additions

of the additional nucleotide on the mRNA determines if the mutation results in *missense* (the protein made is not able to function) or *nonsense* (no protein is made, generally because one of the new codons is a stop codon) (see page 107).

❑ *Deletion* A deletion happens when a nucleotide is removed from the DNA. A deletion has the same results as an addition.



deletion

The above three alterations of genes can have the following effects:

❑ *major effects,* because they produce no protein or vastly different protein (which can be lethal or cause genetic diseases), or

❑ *minor effects,* because the protein produced is only slightly different or the protein is not important to the functioning of the organism, or

❑ *no effect,* because they do not really change the codon.

Generally, only substitution mutations result in minor effects, but it is possible for addition or deletion mutations near the ends of polypeptide chains to cause only minor effects. Some scientists believe these minor mutations may cause some of the different alleles we observe.

Biological effects of mutations

Gene mutations that happen naturally are called *spontaneous mutations*. Mutations can also be induced by *mutagens* (MYOO tuh juhnz), such as various chemicals or radiation. According to

Visual 6A-3a and **b** are charts of material in the text. The summary/outline form should help students draw relationships between the various kinds of mutations. Below are some additional notes that parallel the charts:

Notes on Mutations

Critical place: If a mutation happens in the active site of an enzyme or one of the amino acids that bonds with another, thereby giving the protein its shape, it happens in a critical place. A mutation in a noncritical part of a protein happens either when the amino acid that is introduced is virtually the same as the amino acid it replaced or when the section of the amino acid chain which is part of the protein forms a structure which is not critical to the functioning of that protein.

Somatic mutations: If a single cell of a large multicellular organism dies from a mutation, so what? It is estimated that the human body loses hundreds of cells each day to these mutations. Somatic mutations that produce odd proteins may result in problems like birth marks or moles or may produce enzymes which turn on genes which should not be on, which is what is speculated to happen in some forms of cancer. Note that the same factors that cause mutations (mutagens) are also cancer-causing factors (carcinogens). Somatic mutations are common (a person has millions of somatic cells for each germ cell) and cannot affect the next generation (evolution).

Germ mutations: There are far fewer germ mutations than somatic mutations, but they are far more significant in that they can affect every cell of the offspring and are the only possible means of evolutionary change. Stressing the concept that all changes of genes must be random, and must be from a highly ordered state (the DNA to protein sequence is one of the most elaborate, highly organized, efficient systems known to man) to one of less order will help the students understand that evolution by germ mutation, although the only possible method, is impossible.

some estimates, every human has thousands of mutations in his body. Most of these mutations, however, will not affect a person or his offspring.

A **somatic*** (soh MAT ik) **mutation** is a mutation that occurs in the nongamete cells of the body. A mutation in a somatic cell will usually do one of three things:

- *Produce an odd protein.* Some odd proteins either decompose or are given off as waste products. Since most human cells are diploid, most mutations of this sort do not drastically affect the cell: the other allele will still function. This type of mutation may account for certain blemishes or deformities such as moles, and some tumors.
- *Have no effect.* The mutation of a gene that was not working in a particular cell has no effect until that gene is turned on. In some human cells certain genes are never turned on. Many substitution gene mutations have no effect because they do not significantly change the codon.

If a blood-forming cell in an adult mutated to the sickle cell gene, would that person suffer from sickle cell anemia? No. Even though the odd protein may be produced by this cell, many other cells are producing normal protein. Most mutations have no effect because they are somatic and in multicellular organisms.

- *Kill the cell.* The build-up of an odd protein that is poisonous to the cell or the lack of a needed protein results in the death of the cell. Since there are thousands of every type of cell in the human body, the loss of one cell is not noticed.

somatic: (body)

Adam, Eve, and all the living things God made were perfect when they were created. What this means genetically is impossible to tell. What effects the curse of Genesis 3 had on that genetic make-up can only be guessed at. One can only speculate as to the genetic changes needed to arrive at the variety of alleles which exist today. To claim that all the alleles now observable as normal variations (this excludes harmful alleles known to cause deleterious traits, like hemophilia) were present in the original creation is speculation, but it appears defensible based on current genetic information. To argue that God programmed in (possibly at the time of the curse) a specific number of variant alleles that would eventually happen by natural causes (perhaps mutation) and thus permit the normal variations observed today is possible, but highly improbable, according to some Christian scholars. There may be other possibilities. Man's knowledge of the mechanisms of heredity, although it seems vast to the beginning student, is really very limited. (Geneticists are not even sure how some of their techniques work; but because they work, they are used. Many of the techniques now used will seem crude and ineffectual in the future.) As understanding increases, scientists may be better able to determine where the alleles for natural variations came from.

Normal Variations

Where did the alleles responsible for all the various human hair colors, heights, lengths of nose, and body sizes come from? We know that all human genes ultimately came from only two persons, Adam and Eve, and that the alleles for the various traits seen in groups of land animals descended from the "two of every kind" or "seven of every clean animal" on Noah's ark. Beyond that we can only speculate at the origin of the naturally occurring variations we see today.

Some traits appear to have been introduced by mutation. Hemophilia, albinism, and other human genetic disorders apparently result from specific gene mutations. All known mechanisms in cellular genetics appear to prevent mutations, or, when they do happen, to eliminate them. The few inherited disorders we can observe appear to be ones that slip through.

Traits that scientists can reasonably trace to mutations are all harmful to the organism that has them. Since a mutation is a random change in a highly specific coded message, harmful effects are expected. Although genetic disorders may be traced to mutations, many scientists believe that alleles for normal variations cannot be the result of mutation.

In the past, evolutionists may have been justified in believing that only mutation could introduce new alleles. Current genetic observations may point to other sources for normal variations.

Much of the DNA in your cells appears not to be used to code for anything. Past estimates indicated that humans used only about 50% of their DNA, but some modern estimates indicate that humans normally use less than 10%. The unused DNA does resemble genes. Could this coded information be used to change specific alleles into other alleles? Is it possible that if different sections of a person's genetic code are used (see exons and introns, page 104), different traits could result? Is it possible that humans have the genetic information for the "normal" formation of other alleles instead of the ones they are expressing? Some evidence suggests these possibilities, but we really do not know.

Observations indicate that there are both a great variety and specific limits in normal human genetic variations. For example, there are dozens of shades of the various hair colors but there are also limits within which these hair colors can occur.

In order for evolution to be true, the range of genetic variability must be virtually limitless. Evolution demands a mechanism that could, if given enough time, take any gene and change it into virtually any other gene. Based on observations of variations and present genetic understanding, this is beyond the scope of normal genetic variability and is statistically impossible (see pages 199-202).

albino: (L. ALBUS, white)

anemia: an- (without) + -emia (HAIMA, blood)

The Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents that genetic defects are not curable (at this time), but many are treatable. The general information about the specific genetic disorders mentioned is helpful. Some teachers find that using these genetic disorders as examples in their lecture material is an ideal way to cover the Facet's contents.

The terms **genetic disorder (inherited disorder), albinism,** and **sickle cell anemia** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

More information about sickle cell anemia appears on pages 132-33. Also see pages 265-67 regarding malaria.

6A-1

Facets of Biology

Human Gene Mutations – Treatments and Cures

A **genetic disorder (inherited disorder)** is any undesirable function or shape of an individual's body that is caused by a gene or group of genes. Most humans have at least one genetic disorder, if not several. Some genetic disorders are very mild and are even accepted as normal. Shortness, baldness, larger hands, big ears, and some types of birthmarks are a few of the lesser genetic disorders.

A birthmark is considered to be a lesser genetic disorder.

For most genetic disorders there are, at present, no cures. When an individual has a genetic disorder, every cell in his body has the genetic information for that disorder. For the disorder to be cured, the responsible gene or genes would need to be corrected or replaced in all the cells of the body in which that gene is turned on.

Many genetic disorders, however, can be *treated*. Treatments of genetic disorders relieve only symptoms; they are not cures. For example, if a person inherits hemophilia (see pages 138-39) there is little that can be done to cure the condition, but today the blood chemicals he cannot make can be supplied to him.

An albino person

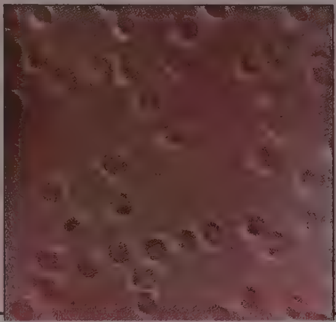
Other genetic disorders are apparent at birth. Perhaps you have seen people with pink eyes, pure white hair, and complexions with a chalky appearance. These people have **albinism**–that is, they lack a dark-colored pigment called melanin, which is necessary to make most of the pigments which color various parts of the body. Their eyes and skin appear pink because the red of their blood shows through. An *albino** (al BYE noh) person has 2 recessive, mutant genes for the albino trait. This is an example of 1 gene controlling several characteristics.

Most albino persons live normal lives, but they must avoid long exposure to sunlight. Lacking melanin, their cells can be harmed by strong light. Some albino persons seek to improve their appearance by coloring their hair, wearing glasses or contact lenses, and wearing make-up.

Mutations which cause human disorders are generally harmful. There are, however, special circumstances under which a harmful mutation can be considered beneficial.

The **sickle cell anemia*** trait is believed to be the result of a mutation in a gene for hemoglobin production. The substitution of 1 nucleotide in only 1 codon for 1 of the proteins which go together to make the hemoglobin molecule results in sickle cell anemia. Careful investigations have traced the sickle cell anemia gene to several tribes in the northern part of Africa.

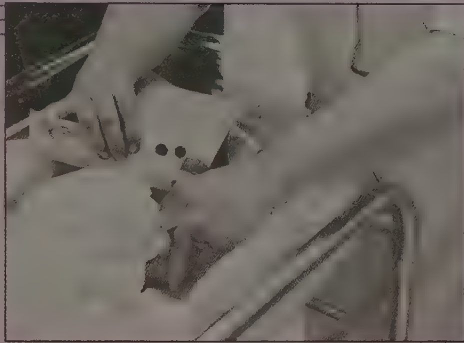
Normal blood cells (left) and sickle-shaped blood cells (right).



African people with normal hemoglobin generally suffered from malaria, a harmful blood disease caused by a tropical parasite. People with the sickle cell trait, however, appear to be immune to malaria because the parasite cannot live in their blood. People in these tribes who were homozygous for the sickle cell allele died, and those homozygous for normal hemoglobin died of malaria. The advantage of being heterozygous accounts for the sickle cell trait's being found in almost every member of certain tribes. In the U.S., however, the bearers of the trait lack this advantage, since malaria is not a major problem except in tropical areas.

Not all mutations are recessive. An example of a dominant mutation in humans is *achondroplastic dwarfism*. People with this condition have bones that do not develop properly; consequently, their trunk is of normal size, but they have short arms and legs, large misshapen heads, and swayed backs. Their intelligence is unaffected. Although the dwarfs mature physically, their reproductive rate is lower than the reproductive rate of normal people. There is little that medical science can do to help these people.

Some genetic disorders are not apparent at birth. A person with *Huntington's chorea,* for example, usually will not express this dominant gene until he is over thirty years old. A man named Huntington first described the symptoms of this disorder: the slow loss of mental ability, the loss of voluntary control of muscular activity, and occasional spasmodic movements. People with this genetic disorder know they will die after an extended, humiliating period of uncontrolled muscular activity and loss of mind. At present there is little that can be done for people with Huntington's chorea.



In many hospitals newborn babies have their heels pricked and their blood tested for various disorders, including PKU.

Still other genetic disorders have treatments which permit the person to lead an almost normal life. For example, insulin injections can be given to those who suffer from diabetes mellitus (see pages 603-4). A person with hemophilia can be supplied with the missing blood chemicals.

Phenylketonuria (PKU), another genetic disorder, can be controlled by diet. In normal human metabolism the amino acid phenylalanine is converted by an enzyme to tyrosine, another amino acid. If a person lacks the gene for the manufacture of the necessary enzyme, phenylalanine is converted to phenylpyruvic acid. Because the lack of this enzyme affects pigmentation, the person with PKU appears pale. When this and related acids reach a certain concentration level in the blood, they are filtered out in the urine.

However, the high blood concentrations of these acids are toxic to a young child's developing brain. A child with untreated PKU loses mental ability and becomes severely retarded. Most hospitals test newborn babies for PKU. If a child has this disorder, he is put on a special diet which greatly limits his intake of phenylalanine and therefore limits the phenylpyruvic related acids in the blood. Once the child is about 6 years old, he can eat normal food without brain damage because his brain is no longer growing.

Apparently, there are genetic disorders (such as, certain types of diabetes) caused by the turning off of a particular gene. Perhaps scientists will find a way either to prevent the gene from turning off, or turn it back on. Even then, however, such a technique is a treatment, not actually a cure. Because the defective gene still exists in a person, he will pass it on to his offspring.

Review questions on page 156.

Milk products and various meats contain phenylalanine. One type of artificial sweetener (e.g., Nutrasweet®, Equal®) contains phenylalanine and must be avoided by those who suffer from PKU but is safe for other people.

More information regarding the nature of mutations can be found on pages 199-202 and 206.

Answers–Review Questions 6A-4 *(p. 156)*

1. Radiation (ultraviolet light and X-rays) and certain naturally occurring chemicals can cause spontaneous mutations.
2. **(1)** Addition of a nucleotide in the sequence; **(2)** deletion of a nucleotide in the sequence; **(3)** substitution of a nucleotide (either the order is changed or one is replaced)
3. **(1)** Production of an odd protein (may account for moles and cancers); **(2)** no effect (often the result of gene mutations that involve substitutions); **(3)** death of the cell by build-up of an odd protein which is poisonous or by the lack of essential proteins

A **germ mutation** is a mutation in a cell that is forming gametes (sex cells). Because a germ mutation produces gametes with some genetic change, it will affect every cell in the new individual. Some mutations, which, if somatic, cause either no effect or simply the production of an odd protein, will be lethal as germ mutations. A mutation that kills the cell will, of course, be lethal as a germ mutation.

Elimination of germ mutations

Many germ mutations are eliminated by a *genetic screen.* In haploid organisms a single gene mutation usually results in a total lack of proper protein since there is no additional allele to supply the missing protein. The organism is greatly deformed or it dies, thereby eliminating the mutation. Plant ova and pollen normally grow temporarily in the haploid state. During this period mutations generally cause deformities; thus, seeds are usually not produced from that gamete.

Animals and humans with major genetic disorders die between zygote formation and birth. In humans a child born with an abnormality is said to have a *birth defect.* If the genetic irregularity is lethal, either the zygote does not form or the embryo dies quickly. Some lethal genetic disorders result in the baby's dying in the mother's womb and *naturally aborting,* or the baby's being *stillborn* (born dead). About half of the natural abortions are the result of chromosome defects.

Some babies die very soon after birth as a result of genetic disorders. It appears that God designed into the genetic mechanism of humans (and most organisms) a genetic screen that eliminates many greatly deformed individuals, preventing major genetic disorders from continuing.

Biological Terms

lethal
chromosomal
gene mutation

Changes Affecting Chromosome Numbers
genome
parthenogenesis
euploidy
polyploid
triploid
colchicine
tetraploid
aneuploid
nondisjunction
Down's syndrome (mongoloidism)

Changes Within the Chromosome
gene linkage
crossing over
translocation

Gene Action and Gene Mutations
sex-limited characteristic
gene mutation
somatic mutation
germ mutation

Facet
genetic disorder (inherited disorder)
albinism
sickle cell anemia

Review Questions 6A-4

1. List several natural causes for gene mutations.
2. Gene mutations can affect the code for an amino acid in what three ways?
3. What are three possible results that could be expected if there were a gene mutation in a chromosome of your somatic cells?
4. Why is a germ mutation more significant than a somatic mutation?

Facet 6A-1: Human Gene Mutations–Treatments and Cures, pages 154-55

1. Why is it difficult to cure a human genetic disorder?
2. List several human genetic disorders, and describe the treatments used to overcome the symptoms of the disorders.
3. Some people have said that the mutation that causes sickle cell anemia is a beneficial mutation. What arguments justify and what arguments are against this statement?
4. List several human genetic disorders for which there are no effective treatments at this time.

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4. A germ mutation, which can be lethal, will affect every cell produced from the gamete in an individual. A somatic mutation affects individual cells and tissues, and since the body normally loses and reproduces individual cells, it usually does not severely affect the individual or organism. (If a single cell is injured due to a somatic mutation, its loss is not usually noticed because of the great number of cells and cell types in the body.)

Answers–Facet 6A-1

1. Since every cell of the affected person has the genetic information causing the disorder, curing this disease would involve correcting the genetic make-up of all cells. Treatment of the symptoms of the disease is easier and is currently the only method of dealing with genetic disorders.
2. Hemophilia is treatable with medication; some (like PKU) can be treated by diet changes.
3. It could be justified by pointing out the advantages to people who are exposed to malaria. Those who have the sickle-cell trait, it can be argued, are not benefited in most of the world, and thus are helped only in certain circumstances. Even in the areas where malaria is a concern, however, these people suffer the effects of sickle cell anemia.
4. Achondroplastic dwarfism, Down's syndrome (mongoloidism), Turner's syndrome, sickle cell anemia, etc.

6B-Modern Genetics

The atomic bomb dropped on Hiroshima, Japan, in 1945 began the Atomic Age. Since then scientists have learned much about the atom. Most of us are aware of the great power in the atom as well as the threats of nuclear war and of increased radiation (even from peaceful uses). On the horizon, however, is a more powerful and a potentially more dangerous era: the *Genetic Age.*

The Atomic Age promises great benefits but threatens man with major destruction. The Genetic Age also promises great benefits but threatens man with *change*, which may be for better or for worse. Many scholars, scientists, and theologians are concerned about how genetic information will be used. The most important decisions your generation will make may deal with the use of the information obtained in the Genetic Age.

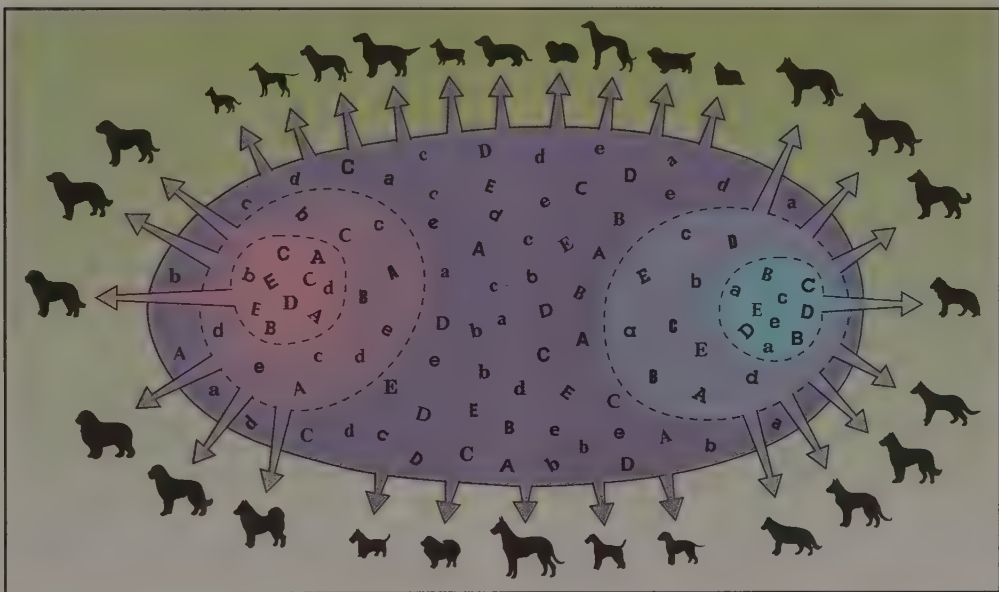
The Gene Pool and Population Genetics

Geneticists often refer to the sum of all the genes that all members of a species of an organism can conceivably possess as the **gene pool** for that organism. Every normal individual has a complete set of genes from the gene pool. That complete set does not have every possible allele of every gene. For example, all the possible genes that Mendel's peas could have had constituted the gene pool for peas, but every pea plant does not have *all* the possible alleles of every gene. A short pea plant (homozygous recessive) does not have the allele for being tall.

The human gene pool has genes for hemophilia in it, but most people do not have this gene. If a person's parents do not have the gene for hemophilia, there is no chance of his having it (unless a mutation occurs). An individual has access to

Gene pool is often a difficult term for students to grasp. Stress that it is a hypothetical concept. Note that access to the gene pool is only through the parents. The individual does not choose his genes from the gene pool.

6B-1 *The dog gene pool. Different dogs are possible because of the large number of alleles in this gene pool. Smaller gene pools exist as "puddles" of this gene pool. Occasionally, "puddles" homozygous for certain genes exist (usually the result of selective breeding), resulting in pure strains of dogs (e.g., collie, dachshund). These purebreds can mate with other members of the gene pool, resulting in hybrids.*



The gene pools on the left have huskier build, longer hair.

The gene pools on the right have thinner build, shorter hair.

The types of letters indicate alleles of a gene in the canine gene pool. The puddles have only certain alleles in them. Offspring of a cross between one of the puddles and the main gene pool would introduce alleles into the puddle. Man maintains puddles by "excluding" such crosses. Other material and some canine illustrations can be found on pages 218, 221-24.

6B-Modern Genetics

Notes-Chapter 6B

The opening of this chapter presents material that may seem a bit vague at first. The material should be covered quickly, but not omitted. Some of the arguments against evolution are based on these topics.

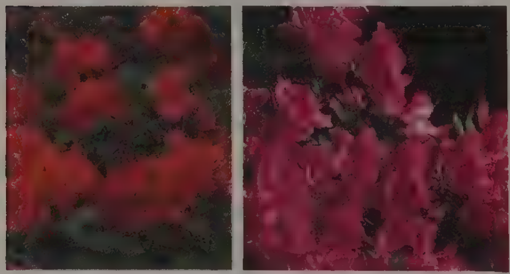
The section on eugenics, however, is essential. In the next few years sperm and ovum donors, surrogate mothers, and even genetic engineering of humans will no longer be novelties worthy of court cases, spots on the evening news, and columns in the newspaper. By the time today's students are considering having children, these will

Objectives-Chapter 6B

- ❑ Describe the concept of a gene pool.
- ❑ Discuss how mass selection, hybridization, and inbreeding affect the gene pool.
- ❑ Define *eugenics* and give historic examples of its practice.
- ❑ Define *genetic screening* and discuss how it is currently being practiced.
- *❑ Define *genetic engineering* and describe genetic engineering techniques being used today.
- ❑ List several artificial reproduction techniques scientists are currently using and some they are seeking to develop.
- ❑ List several problems that may develop as genetic engineering techniques are applied to humans.
- ❑ List several Biblical principles that must be considered when making decisions regarding human genetic engineering.

*From a box.

6B-2 *The wild flame azalea (left) has been bred by mass selection and hybridization to obtain various hybrid varieties (right) often seen in southern gardens.*



Page 153 also deals with variations. Chapter 8B, *The Species and the Kind,* may be helpful background material. Some students, reading the material presented here and then looking at the definition of *variation* presented in the glossary, may have difficulties. The definition in the glossary is more complete, adding information from the previous chapter and hinting at material in Chapter 8.

the gene pool only through his parents, who are two separate accesses to the gene pool. In other words, one parent brings to his children one set of genes, and the other parent brings another set. Some genes in a cross are homozygous, each parent giving the same allele as the other. For some genes, however, the parents give different alleles and thereby produce offspring which are not exactly like themselves. These natural differences between individuals from the same gene pool are called **variations.**

The gene pools of organisms contain both desirable and undesirable traits. For thousands of years the breeding of animals and plants for desirable traits has been a profitable activity for man. The objective of such breeding is to produce offspring that are superior to the parents. Superior characteristics might include greater weight gain, greater milk production, greater resistance to disease, or the ability to survive in an area of low rainfall, late spring frost, or early autumn freezes. Actually, the breeder may want any number of desirable characteristics. He can use any of several techniques to select from the gene pool those genes that will give good traits to the offspring.

Most of the cited examples of evolution are merely the results of breeding. Carefully point out to the students the difference between creating a new gene and isolating a pure strain of an existing gene.

Mass selection

Ancient peoples selected the most desirable animals and plants from the herd or field as *breeding stock.* This method of selecting breeding stock, called **mass selection,** continues to be used today. The loblolly pine, for example, is a valuable lumber tree that grows throughout the southern United States. Unfortunately, southern pine beetles often attack forests of the loblolly pine and in a few weeks can kill thousands of trees. Often, only a few trees remain alive after an epidemic. The remaining trees apparently possess something that repels the beetles. Seed that is harvested from those trees is being used in a breeding program to develop a strain of loblolly pine that is resistant to the southern pine beetle.

6B-3 *The pine bark beetle and the destruction these insects can do to loblolly pines*

Let us suppose the obstacle to the tree farmer is, instead of insects, drought. What pine tree seedlings can survive and grow in a dry climate? In an isolated, low-rainfall area of Texas, the "lost pines" grow to a size that is useful in the lumber industry. The Texas Forest Service collected seeds from trees among the lost pines and grew seedlings. They tested the seedlings for their ability to survive under dry conditions and compared the results to seedlings from other areas. The lost pine seedlings survived, while others did not. Each winter the Texas Forest Service sells thousands of "drought-hardy" pine seedlings grown from seeds taken in the lost pine area. The use of lost pine seedlings is another example of mass selection.

Notice that mass selection attempts to cultivate an already existing trait, *not* to develop a new trait. Breeders are seeking a pure line of some characteristic already in the gene pool, *not* expanding the gene pool. Creationists and evolutionists agree that mutation is the only way to introduce *new* genes into the gene pool. Mutation, however, is not necessarily evolution (see pages 199-202, 206).

be options the world will be counseled to consider.

The topic, however, is not as black and white as "Thou shalt not steal." In eugenics many things come into play, and all must be considered in order to make a proper judgment and take a Scriptural stand. Most of the major points have been touched upon in the text. One ideal way to deal with this material is to have the students read the text and then have group discussions (possibly based on hypothetical case studies–even futuristic case studies).

The next best method would be to have the students read the material and then have a summary lecture. An alternative is to have students read the material and write position papers in answer to a carefully structured case study; or divide the class, and give a different case study to each group.

Some teachers may be able to have the students and their parents read and discuss the material. Some parents balk at such assignments ("Why do you think I'm paying you?"), while others will recognize this as their God-given responsibility. At the very least, students should be expected to read the material.

Facet–Chapter 6B

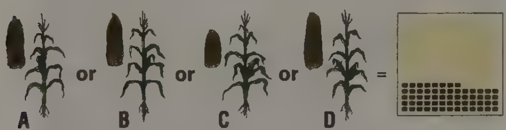
The Facet on genetic engineering may appear technical at first, but if proper teaching of the material in the past few chapters has preceded it, there should be no problem. An understanding of this material will become more crucial as genetic engineering becomes common in society. Do not skip this material.

Hybridization

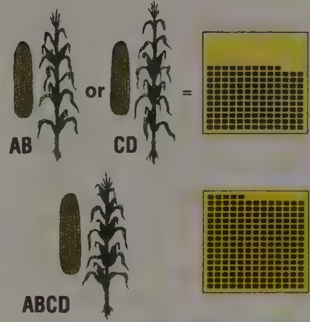
Hybridization (HYE brid uh ZAY shun) is the crossbreeding of two genetically unrelated individuals. The offspring of such a cross is called a *hybrid.** Hybridization often involves two varieties of the same species. Crossing two strains of corn, crossing two different kinds of apples, crossing two different varieties of chickens, and even the marriage of an Egyptian woman to an Englishman are examples of hybridization of two members of the same species.

The hybrid offspring of animals or plants often have characteristics superior to either parent. This superiority is called **heterosis** (HET uh ROH sis), or *hybrid vigor*, and may involve such things as greater resistance to disease, larger bodies, more milk production, or more crop yield per acre.

Plant breeders have used heterosis to improve crop yield. Corn, a wind-pollinated crop, is usually heterozygous for many traits. Since each corn kernel is fertilized by a different pollen grain, a single ear may have kernels with many different phenotypes. Before careful breeding, 120 bushels per acre (bpa) was an average corn yield. **Inbreeding**–the mating of an organism with itself or with close relatives–can, in time, produce pure strains. **Pure strains** are organisms which are homozygous for various traits. Four different pure strains of corn (labeled *A*, *B*, *C*, and *D*) were produced. These pure strains, however, were of low quality. Some of them produced only one small ear per plant, and the ears had very small kernels. The average yield was only about 60 bpa.



When breeders crossed strain *A* with strain *B*, heterosis produced a crop yield of about 140 bpa. The same was true of the cross of the *C* and *D* strains. But mating the offspring of the *A* + *B* cross with the offspring of the *C* + *D* cross produced a superior corn with a yield of about 200 bpa. This type of hybrid corn is the type most often grown in the United States. Controlled breeding by seed companies supplies hybrid corn seed to farmers. Farmers who try to grow their own corn seed without careful breeding techniques, get poor quality corn, much like the crops before controlled breeding.



In animals, close inbreeding (mating of parents to their own offspring) often results in inferior offspring. Although organisms that are homozygous for good traits are desirable, close inbreeding may also result in organisms that are homozygous for poor traits. Careful inbreeding for generations has produced relatively pure strains of certain dogs, cattle, chickens, horses, and other animals. These domesticated animals possess characteristics man considers desirable. Man's preference for animals with certain traits and his indifference about other traits has determined the lineage of animals such as cows, sheep, and chickens. These animals are now in some respects inferior to the wild stock from which they came, in that many of them are no longer able to live without man's care.

6B-4 *Miniature horses, which stand about a foot tall, are the result of careful breeding.*

hybrid: (offspring of different parents)

Hybrids between organisms that are not of the same species are discussed on page 145-46.

It is well known that mutts are often healthier and suffer from fewer deformities than the purebred varieties of dogs. This is an example of *hybrid vigor.*

Drawings of corn are purely diagrammatic. Corn usually does not have more than three ears per stalk. The increased yield is because of larger ears.

A significant point–Inbreeding sacrifices certain traits for others. This domestication permits a high yield of desirable traits but usually significantly affects the organism in other ways. This can easily be considered part of the "subdue and have dominion" command. The organisms chosen by man for his use are Scripturally under man's jurisdiction. Of course, he is obligated to care for such animals after he domesticates them (more on animal rights and related topics, pp. 488-91).

Review Questions 6B-1

1. Explain why a single organism cannot have one of every gene from its gene pool.
2. Can a breed be improved after many generations of mass selection? Why or why not?
3. Why does inbreeding often produce inferior-quality organisms?

Answers–Review Questions 6B-1

1. An organism has access to its gene pool through its "parents" and can only receive genes carried by its "parents." Also, each individual can normally have only two alleles for a particular gene, but there are many alleles in the gene pool.
2. Mass selection can develop a purer line of a certain desired trait that already exists. By developing this line, the breed can become more desirable and better able to survive and meet man's needs; in that sense, it is improved. It does not develop new traits.
3. Inbreeding may result in organisms that are homozygous for bad traits. Even those organisms that have desirable traits may not be able to live without man's care.

eugenics: eu- (well) + -genics (birth)

*Theodore Roosevelt, *The Works of Theodore Roosevelt* (New York: Charles Scribner's Sons, 1926), XII, p. 201.

Eugenics is one of the primary areas of concern for Christians. Progress is made so quickly that it is difficult for specialists to keep up. There are some points that Christians definitely need to oppose; there are other points that Christians are uncomfortable with because they are new, but there is no Scriptural reason for considering them bad. Christians must sort the wrong from the acceptable. This requires an understanding of both Biblical principles and scientific and political developments.

If Christians understand the issues, Satan will not be able to fool them, causing them to ignorantly accept something wrong until it is too late to do something about it. Knowledge will also foil another of Satan's tactics–having Christians take a stand that they claim is Scriptural when actually their stand is not supported in Scripture. This material is designed to present the Scriptural principles and some of the most recent scientific advances as well as what they portend.

Eugenics

The term **eugenics*** (yoo JEN iks), meaning "good genes," is traditionally applied to efforts to improve the human gene pool. This science is by no means new. Plato felt that "the best of both sexes ought to be brought together as often as possible and the worst as seldom as possible" and that inferior offspring ought to be abandoned. As the Roman birth rate fell while conquered peoples multiplied, Caesar offered money to Roman mothers to have children to keep the "superior" Roman population growing.

Probably one of the most wide-spread eugenic endeavors was conducted in the 1930s by Adolph Hitler. The German dictator's systematic killing of millions of Jews resulted from his desire to eliminate what he believed was an "inferior race." At the same time in special camps, scientists of the Third Reich were inbreeding humans of "superior" German stock to form a "super race." What is now known of these experiments (most of the records were destroyed) indicates that the mass selection and inbreeding techniques which these scientists used did not produce a super race. Of course, the experiments lasted only a few years, not enough time for the many generations needed for effective selective breeding.

Consider this opinion:

> I wish very much that the wrong people could be prevented entirely from breeding; and when the evil nature of these people is sufficiently flagrant, this should be done. Criminals should be sterilized and feeble-minded persons forbidden to leave offspring behind them. . . . The emphasis should be laid on getting desirable [*sic*] people to breed.*

This statement was not made by a Nazi in the 1930s but in 1913 by the American patriot Theodore Roosevelt. Although he was a great leader in other ways, he, with most of the American upper class of the early 1900s, thought that the many immigrants from Europe, Scotland, Ireland, and the Orient were a threat to American society.

As early as 1869, a group of 91 American men and women signed a pledge to participate in "matching those most advanced in health and perfection." By 1900 many such "eugenic farms" had been established to "improve the blood lines" of Americans.

American presidents, respected scientists, well-known educators, and thousands of others expressed their belief in and gave encouragement for "modern scientific eugenic" activities. Remember that Mendel's papers were rediscovered about this time. These people believed that coming up with ideal humans would be about as simple as obtaining a pure strain of round, green peas. It might take longer, they admitted, since there were more traits to deal with and since people reproduce more slowly than pea plants, but this was all the more reason to get started right then.

Additional genetic experiments with animals, however, have shown that most of the practices of eugenic leaders of the early 1900s were contrary to what would eliminate "bad blood" (actually bad *genes*) and encourage "good blood." They also failed to recognize man's environment and spiritual nature as major influences on human behavior and well-being.

The Second World War, with Hitler's atrocities, put a stop (at least temporarily) to most major eugenic activities in the United States. But today, advanced techniques are making eugenics not only a possibility but also a subtle reality in present American life. We shall examine some of the genetic activities which politicians and scientists are using and some they plan to use to improve the human gene pool.

Genetic screening

Genetic screening is the determining of an individual's genetic make-up. In America today, there are hundreds of genetic counseling centers which use genetic screening to be able to supply people with information about either themselves, their relatives, or their future children. Even using the most modern techniques, however, people learn about only a few of their genes.

At present there are three basic genetic screening methods that are widely used:

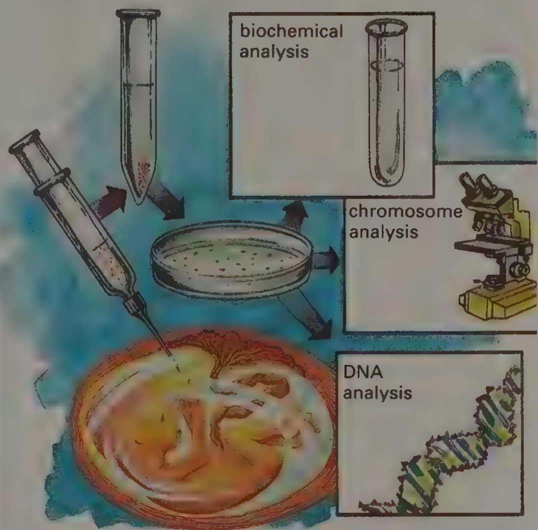
❑ *Analysis of the pedigree.* By obtaining information about the individuals and their families,

6B-5 *Tay-Sacs disease, which is found primarily among certain Jewish groups, is caused by a recessive gene. Because of an enzyme deficiency, homozygous individuals go blind and die as children. Carriers have a low level of the enzyme. The amount of the enzyme can be determined by sampling tears or testing blood. The information can be used to predict the likelihood of a Tay-Sacs offspring.*

genetic counselors construct pedigrees. Sometimes people can be tested to determine their genetic make-up regarding a particular condition. If the inheritance pattern of the trait is known, the counselors can then make accurate predictions regarding the probability of individuals having the trait. Many genetic disorders, for example, are simple recessive traits. By constructing pedigrees, a genetic counselor can tell prospective parents the percentage of their offspring that should have the trait, carry the trait, or be free of the trait.

6B-6 *In ultrasonic scanning a device rubbed over the woman's stomach releases sound and picks up the echoes that bounce off internal structures. The data is used to produce a sonogram, like the one of the unborn child above. Sonograms can tell if the child is developing properly or has been damaged by injury.*

❑ *Analysis of the unborn.* Today there are several methods of learning about a child before he is born. **Ultrasonic scanning** or *sonography* (sohn NAWG ruh fee), the use of sound to make "shadow pictures" similar to sonar, and **fetoscopes**, a fiber-optic device inserted into the womb, are used to get pictures of the unborn child. The pictures can reveal genetically related deformities. **Amniocentesis** involves removing some of the fluid which surrounds the unborn child. The child's cells in this fluid can be used to produce karyotypes and look for chromosomal defects such as Down's syndrome. The fluids can be chemically analyzed to determine other genetic conditions.



6B-7 *Amniocentesis involves removing some of the fluid from around the unborn child to diagnose disorders. The fluid contains cells and chemicals produced by the child. The sex of the child, abnormal chromosomal conditions, and metabolic disorders can be determined before the child is born. Sometimes treatment can begin by changing the mother's diet or even transfusing the unborn child's blood if needed. Amniocentesis is not without risk. The procedure is done only if a physician feels it is necessary.*

Another form of prenatal (before birth) diagnosis is the *chorionic villus biopsy* in which a tiny section of the chorion is removed and analyzed.

The fetoscope is also used, in conjunction with other instruments, to withdraw blood samples from the unborn child to determine if he is a hemophiliac and even to carry out intrauterine (inside the uterus) surgery and blood transfusions.

From the amniocentesis sample it can be determined if an unborn child has Tay-Sacs disease or PKU. A mother whose unborn child has PKU is sometimes encouraged to change her diet to help her child.

There are significant ethical problems with genetic screening. What if the physician is looking for one condition but finds another? Should he always tell the patient? Telling the patient might be good in some circumstances and not good in others. Physicians have been sued for not telling parents of a disorder their unborn child had which was discovered while looking for another condition. Some people want information regarding their unborn children so that they can make a decision about abortion. Abortion is discussed on pages 639-41.

The section on artificial reproduction contains information that some will find disquieting. Some teachers may opt to have students read the information but not comment about it in class. Others may find a brief presentation acceptable. If possible, a guided discussion is recommended. Some teachers may wish to put off covering this topic until they cover the material regarding the sanctity of human life (p. 639) and human reproduction (Ch. 24). It may be wise to preview this section before dealing with it. Many of the notes presented here in the Teacher's Edition are suggested arguments for and against various ideas that might come up in a classroom discussion.

The agricultural advantages to the various forms of artificial reproduction are numerous. Developing these techniques permits man to have improved organisms available much sooner than would be possible using normal reproductive techniques (related material, pp. 328-30).

Millions of people in the United States have been born as the result of artificial insemination. Many women have selected sperm from a sperm bank rather than have the sperm of their husbands, often because of a known genetic defect in the husband's lineage. Is this practice wrong? Why or why not? It is difficult to take a definitive position.

Today some unmarried women have been artificially inseminated. The Scriptural teachings regarding the family can be used to argue against this practice. These arguments, however, hold little weight with many unsaved people. Many of them look upon Christians as backward for not condoning artificial insemination of unmarried women. Because artificial insemination can be misused in this way, is all artificial insemination to be condemned as wrong?

Human artificial insemination is becoming a hot topic. If sperm known to have good genes is available, why not use it to produce children rather than take chances with the potential problems of unknown, possibly bad genes? If there is a 25% chance the child will have a deformity, does that make it acceptable for a Christian wife to have artificial insemination with another man's stored sperm? Does the severity of the potential disorder have any weight in such decisions? Does it make any difference if the sperm donor is dead?

A major objection to test-tube fertilization is the "leftovers." Physicians often fertilize several ova at once. The others may be stored. If the first implantation does not result in a pregnancy, the others are ready as needed. What is to be done with the unused embryos? If fertilization is the point at which the soul is imparted to the individual, then humans are killed when these embryos are destroyed. Although theologians disagree as to the exact point at which an individual's soul and body come together, it does happen at some time before birth.

Suppose a couple who had zygotes formed and stored gets divorced. Who gets the embryos? If the woman decides to become pregnant with one of them, does the man have any responsibility to the child? Should the embryos be killed? If so, is this the same as abortion? Should the embryos become wards of the state for the government to find a "home" for? Should they just be kept until they are no longer usable (several months to a couple of years)? Is that the same as abortion? The problems are numerous. Should the technique be restricted to "one embryo at a time"? Some scientists want to experiment with the fertilized ova that have not been used for implantation. At present it is illegal for them to do so in the United States and most other countries. (See additional information on the following pages of this chapter regarding human genetic experimentation.)

❑ *Analysis of the newborn.* A baby undergoes a number of tests soon after he is born. Some tests are conducted visually; other tests require blood or urine specimens. The results of these tests give the physician information needed to treat those infants who have certain genetic disorders.

Prospective parents can use the information obtained by genetic screening as they plan their families. By knowing that a child has a genetic disorder, parents and physicians could begin proper treatment at birth, if not before. Some people see this as a good form of eugenics. If those individuals with major genetic deformities did not reproduce, the percentage of genes causing the deformities in the gene pool would decrease. Such knowledge, however, is not without problems, as we shall see in later sections of this chapter.

DNA Probes

The methods of genetic screening may soon be outmoded by more refined techniques. Although not yet readily available for many genes, scientists can use *DNA probes* to determine if a person has a specific gene.

A DNA probe is a small piece of DNA that has known base sequences and can be marked with radioactive substances. When a probe is placed with specially treated DNA from the person being screened, the probe will line up with DNA that has a corresponding sequence of bases. If that sequence does not exist, the probe will not line up with any DNA. Using DNA probes, scientists hope to be able to determine if a cell contains specific genes. This procedure could eliminate much of the uncertainty involved in genetic screening today.

Artificial reproduction

Artificial insemination (in SEM uh NAY shun) is the mechanical injection of sperm into a female's body. It has long been practiced on animals in laboratories and has been used in farming for many years. Artificial insemination is often used in cattle breeding. Cattle sperm can be frozen and stored. Today cattle breeders can have cows produce calves from bulls that have been dead for years.

Human artificial insemination is over 30 yr. old. Each year thousands of women are artificially inseminated, most because of medical reasons. Few Christians object to artificial insemination between a husband and wife because Biblical principles do not appear to be violated.

Women can also be inseminated with sperm from men who are not their husbands. Human sperm can also be frozen and stored. Women have had children whose **biological father** (the man who supplied the sperm) has been dead for years. Some Christians contend that it is immoral for a woman to be artificially inseminated with the sperm of a donor who is not her husband. Those who condone this form of artificial insemination argue that true purity is not violated by this clinical technique.

Removing an ovum from a female's body is also possible. This ovum can then be fertilized by sperm in a laboratory. If the resulting zygote is implanted in the female's body, it can develop and be born. Scientists can also freeze and store ova. A cow can be forced to produce a large number of ova at one time. All of the ova can then be removed, frozen, and even shipped to other areas. When thawed, they can be fertilized with the sperm from one bull and then placed in different cows to develop. An entire herd can be bred at one time from one set of parents thousands of miles away, or even long dead.

Ova has also been removed from a human female's body, fertilized by human sperm, and then implanted in the woman's body. This process is called **test-tube fertilization** or *in vitro fertilization* and has been used to make childbearing possible for women who lack certain reproductive structures. Few Christians object to the test-tube fertilization of the wife's ovum with her husband's sperm or the implantation of the zygote into the wife's body if physical conditions warrant the use of such techniques.

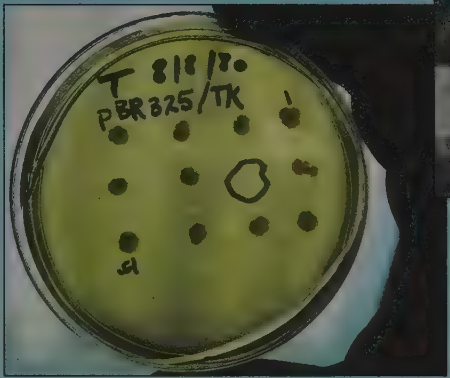
A person who is the result of test-tube fertilization, however, is not a true "test-tube baby." At this time no human fetus has been nurtured until birth in a test tube, but the techniques for doing so may be forthcoming.

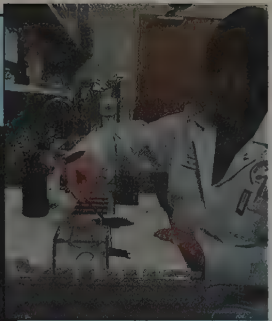
6B-1 FACETS OF BIOLOGY

Genetic Engineering

Genetic engineering is the manipulation of genes by methods other than normal reproduction. There are several methods of genetic engineering that are currently being used and others that are being developed.

Recombinant DNA is currently being used in a technique in genetic engineering. When sections of DNA from two different sources are joined together, the piece of DNA that is formed is called recombinant DNA.





Scientists test the growth of genetically engineered bacteria to see if the gene they wanted is present.

Scientists have found certain enzymes that can snip DNA. These *restriction enzymes* (over 500 different types are known) snip DNA at specific base sequences, leaving several nucleotides unpaired. These unpaired bases often form what scientists call a "sticky end." Another DNA molecule that has been snipped with the same restriction enzyme will have a complementary "sticky end." The 2 complementary "sticky ends" can combine, forming a recombinant DNA molecule.

Using restriction enzymes, scientists can snip genes out of chromosomes and insert them into other chromosomes, even chromosomes of other organisms. Although the process is still in developmental stages, and much of the work is trial and error, genetic engineering using recombinant DNA has yielded some valuable products with promises of more.

An example of the use of recombinant DNA is the manufacture of the protein *insulin,* a chemical essential for the proper use of sugars. Insulin is normally produced in the pancreas, but people who suffer from *diabetes mellitus* either do not make insulin or cannot make adequate insulin and require insulin injections.

In the past, insulin has been obtained from pig pancreases for people who suffer from diabetes mellitus. Pig insulin works well for most diabetic patients. Some people, however, are allergic to animal insulin and have had to be treated with human insulin obtained from donated blood, a very expensive source.

Scientists have taken human cells and used restriction enzymes to snip out the insulin gene. They have then inserted the human insulin gene into a *bacterial plasmid* (a small, circular piece of DNA, similar to a chromosome). The genetic material of the living bacterium now contains a new gene. As the genetically engineered bacterium grows, it produces insulin along with its own proteins. Since the bacterium has no use for the insulin, it collects within the cell.

Bacteria grow and divide rapidly. Plasmids also replicate and divide as the bacterial cell divides. Thus, cultures of insulin-producing bacteria can be grown. When the bacteria are killed, the insulin can be extracted. Even though bacterial cells are used to produce the insulin, the protein produced is human insulin, since its production was directed by a human gene.

Using recombinant DNA, scientists can now implant genes into genomes of other organisms. Moving genes back and forth between bacteria is relatively easy. Moving genes in plants and animals is more complicated. Recently, scientists found a bacterium which contains a plasmid that enters a plant cell and causes tumors. By snipping out the bad gene and then splicing a good gene into the plasmid, it serves as a *vector* (a gene carrier) for moving the good gene into the genetic make-up of the plant.

This Facet presents the potential benefit and possible harm of current and impending genetic technology. This material is significant because of its current uses and potential abuses.

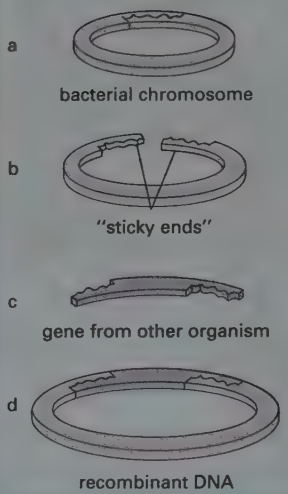
The terms **genetic engineering** and **recombinant DNA** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

See *crossing over* on page 149 and *translocation* on page 150. Mutation-causing chemicals and even the manipulation of chromosomes with colchicine can be considered genetic engineering (see p. 144). Today these are often omitted from the genetic engineering concept.

The human insulin gene in the bacteria is actually in a plasmid, a circular section of DNA not attached to the chromosome. The plasmid reproduces as the cell does and behaves the same as the F⁺ factor, another plasmid (described on page 232).

Scientists hope to use the plasmid to implant the genes enabling freshwater crops (glycophytes–"sweet-water plants") to be salt-water tolerant (halophytes). Thus many areas that cannot grow plants could be cultivated, perhaps even using sea water for irrigation.

Recombinant DNA in Bacteria



Scientists use restriction enzymes to recognize specific sections of DNA in the circular bacterial chromosome.

The restriction enzyme snips open the chromosome, leaving "sticky ends."

A gene from another organism that has been cut with the same restriction enzyme has the same "sticky ends."

When placed together the gene and the chromosome combine forming recombinant DNA.

Using this technique, scientists hope to take genes that cause a desirable quality in one plant and implant those genes into another plant. For example, leaves of some plants produce chemicals that make them resistant to certain insects. Perhaps the genes needed to produce this chemical can be put into crop plants that are susceptible to leaf-eating insects.

In 1982 scientists were able to take the growth hormone gene of a rat and introduce it into fertilized mouse eggs. These genetically engineered mice grew and became two to three times larger than normal mice from the same litter. Other attempts with recombinant DNA genetic engineering of animals have met with limited success. There are many genetic mysteries scientists do not yet understand. Many genes appear to work only if they are preceded by specific genes on the chromosome or occur in certain sequences.

Human genetic engineering using recombinant DNA is just beginning. Lesch-Nyhan syndrome is a rare genetic disorder in which people lack a single enzyme. The symptoms include kidney damage, gout, cerebral palsy, uncontrollable gnawing of fingers and lips, and pounding the head. Death comes before the person is 30.

Scientists have taken cells from Lesch-Nyhan children and used viruses as the vectors to introduce the normal gene into those cells. Investigation continues regarding the possibility of using the virus to put the normal gene into humans and hopefully overcome the trait. People with this and similar genetic diseases are often willing to permit scientists to experiment with almost anything that holds promise for them.

Genetic engineers do more than move genes. By taking a protein apart, amino acid by amino acid, scientists can now determine the genetic code necessary to make that protein. Using a specific nucleotide, a gene is made which (when put into the chromosome of a bacterium) makes the protein. Perhaps scientists will someday be able to design proteins and then make genes to produce them.

Many scientific and political groups are concerned about the effects of genetic engineering. Tampering with the genes of an organism could give it unknown and potentially dangerous characteristics. For example, a scientist could accidentally produce an organism capable of causing a harmful disease while experimenting with a harmless organism. Experiments on animals and plants could produce harmful organisms that could alter the balance of life on our planet. Great care must be taken in this type of experimentation.

Scientists believe that they will be able to manipulate human chromosomes and genes within your lifetime. (To a limited degree it is already happening.) Some scientists predict that zygotes with defective genes will be able to have the bad genes removed and good genes introduced into their genetic material. When this ability has been developed, why not design the child to be tall, strong, intelligent and to have other traits that are deemed "desirable"? We may even design him to have some "desirable" nonhuman characteristics, such as the ability to digest cellulose. Such would be the ultimate in genetic engineering. But is this acceptable?

Review questions on page 167.

Caution students to be careful of criticizing people with Lesch-Nyhan syndrome who allow experimentation on their bodies. Most people are willing to do almost anything to be cured of a disease, especially if the diagnosis is death. Yes, God can work miracles to cure these people, but God also expects man to use his knowledge to cure diseases. If one takes the position that someone suffering with Lesch-Nyhan syndrome should be healed only by God, then the logical parallel is that no one should take any medicine, because he might be healed when God did not want him healed. The argument can proceed that antibiotics are known to cure diseases, but what the Lesch-Nyhan syndrome sufferers are doing is not known to cure the disease. But someone, either after much animal experimentation or from desperation caused by a terminal disease, had to be the first to try antibiotics. Was he sinning? (See information about animal experimentation, pp. 490-91. More about medicines and drugs, pp. 252-53, 615-26.)

One of the major problems with this involves exons and introns (p. 104). These, however, are not problems with genes used by bacteria. Presently, most genetic engineering involves bacteria. The procaryotes seem to have simpler devices for turning genes on and off than do the eucaryotes.

Most genetic engineering has been done on "genetically crippled" organisms. This means that the organism has had mutations which cause it to be dependent upon laboratory culture. One of the most frequently used bacteria is *E. coli*, a species commonly found in human intestines (see p. 232). The genetically crippled bacteria cannot live in humans or anywhere outside of the laboratory. Thus, if an unwanted gene gets into the bacteria, it will not be able to "escape" from the laboratory and get into the environment.

In some instances of test-tube fertilization, the ovum is supplied by a **biological mother** but the zygote is implanted in another woman who serves as the **surrogate mother.** Some Christians object to biological mothers serving as ovum donors. The arguments regarding ovum donors are about the same as those for sperm donors. Today some women serve as surrogate mothers for other women who cannot or do not wish to become pregnant. Many Christians object to surrogate mothers because the Biblical principles of the family are ignored.

The "Genetic Age": dream or nightmare?

A world populated with people who are strong, healthy, and intelligent does sound like a dream. The medical profession has been working toward this goal for hundreds of years. But now with genetic engineering and artificial reproduction, the prospects of achieving the genetic dream appear near. Much of the technology is already known. If the Lord tarries, decisions will need to be made regarding the use of the technology that scientists hope to perfect in the near future.

In the sixteenth century Sir Thomas More wrote *Utopia** (yoo TOH pee uh), a book that describes an ideal society. We now use the word *utopia* to refer to any ideal society. Many secular scientists believe that mankind will reach utopia through science and that genetic engineering will be a major tool in doing so.

In the early 1900s science fiction writers wrote several *dystopia** (dis TOH pee uh) books such as *Brave New World* by Aldous Huxley and *1984* by George Orwell.* These dystopias illustrate the problems that might arise if mankind possessed great scientific and genetic knowledge. In these books, corrupt man uses this knowledge to form a wicked, oppressive society rather than a perfect world. Interestingly, although the authors wrote their works in the early part of this century, they portrayed technology much as today's authors do. The "super people" in these books turn to science and their world for deliverance from problems. Deep in pride, they turn away from God.

Man's power over animals, plants, and even his physical self, however, cannot make him truly good. Only Christ can save him and give him a new heart. No matter how friendly, strong, intelligent, and disease- and disorder-free man is, his righteousness is nothing but filthy rags unless he has a regenerated, cleansed soul. "For all have sinned, and come short of the glory of God" (Rom. 3:23).

The problems of eugenics

Eugenics may be unable to produce for mankind the improvements it promises. Recall that artificial domestic breeds develop weaknesses that make them dependent on man. Likewise, though scientists may someday successfully breed man for intelligence, strength, or other traits, what traits will be sacrificed? If eugenics is practiced widely, the gene pool will shrink as bad traits are eliminated. In that shrinking, man's resistance to disease and his adaptability to different environments may weaken. Man might become like his domesticated animals: dependent on a controlled environment.

utopia: u- (Gk. OU, not or no) + -topia (TOPOS, place)

dystopia: dys- (Gk. DUS-, bad) + -topia (place)

*Because of their philosophies and morals, most popular dystopias are not recommended as high school reading.

An example of negative utopia that some Christians find acceptable and which high school students could read is C.S. Lewis's *That Hideous Strength,* the third part of his space trilogy.

To some people surrogate motherhood is merely an extension and modernization of the adoption process. Many people feel the difficulties of pregnancy can be easily overcome by surrogate motherhood. If one wants a child using the good genes available from donor sperm and ova, why not also pay the extra to have someone "do" the pregnancy too?

Many Christians claim that this contradicts the Biblical principles of the family. But a Biblical family can be based on adopted children. Biological parenthood or experiencing pregnancy is not required to establish a Biblical family. These processes do, however, strengthen the family. That is not to say that families with adopted children are weak. An adopted child may be a special blessing to the family that takes him in. Through adoption, the family can remove a child from a potentially bad situation that is not of his doing. Surrogate motherhood, however, involves other factors. ▶

Answers–Review Questions 6B-2 *(p. 167)*

1. **(1)** Analysis of prospective parents includes studies of pedigrees of prospective parents and genetic tests to make predictions as to the possibility of their having children with disorders. **(2)** Analysis of the unborn child is made by removing a drop of the amniotic fluid and analyzing it to detect Down's syndrome and other disorders. **(3)** Analysis of the newborn child is made by testing the newborn child's blood for disorders such as PKU.
2. **(1)** Amniocentesis involves taking fluid from around an unborn child and analyzing the cells the fluid contains. **(2)**

*"Making Babies–the New Biology and the 'Old' Morality," *The Public Interest,* Winter, 1972, pp. 53-54.

▶ On what ground can one claim that a child who is the result of test-tube fertilization and/or surrogate motherhood is not also able to provide a special blessing? Many Christian couples believe they can have children only if God sends them or if they adopt. Otherwise, they are not to have children. But those who feel this way must be careful not to equate their opinion with doctrine which must be accepted by others. Scripture does not appear to take such a stand. The current generation of Christian scholars needs to address this and similar issues. A class discussion could be profitable.

Consider compiling in class a list of arguments one can expect worldly people to use to support eugenics and a parallel list of how Christians should refute these arguments. Christians can agree with some arguments supporting eugenics; other arguments cannot be condoned.

With today's moral framework, someone may soon suggest that people be produced only on eugenic farms. This may sound logical, but it would destroy the family concept. The government would not rear children according to Biblical principles.

Since eugenics–like all sciences–cannot make decisions, man will have to make the difficult decisions about which traits will be eliminated. Should sickle cell anemia be eliminated? The trait is disadvantageous in the United States but is of value where malaria abounds. Strength and intelligence are desirable, but should everyone be a muscular genius? Diversity has encouraged human achievement. Many people with undesirable traits, in desiring to compensate for them, have excelled in their fields. Paul's "thorn in the flesh" (II Cor. 12:17) was perhaps one such undesirable trait, but it promoted Paul's spiritual progress.

Christian consideration of eugenics

Some Christians condemn human genetic engineering, artificial reproduction, and the like because they consider these techniques "unnatural." But like X-rays, surgery, and all of modern medicine, these genetic techniques are simply tools in man's hands that God can use. If used within the bounds of Scripture, if used to correct deformities or for morally acceptable therapeutic purposes, these tools would find few opponents. But, just like any other tool, these genetic practices can be misused.

Our government is actively involved in genetic research. Politicians point out that our enemies perform such research and that we can ill afford to fall behind. But one of the problems with eugenics is its potential for governmental abuse, as described in the dystopias. Government is understandably interested in eugenics, for it would assist in governing. But some possible results of government involvement are frightening. Restrictions on childbearing and other domination of the family would contradict God's intent that parents rear families according to His will. Through eugenics, government might also attempt to eliminate "unacceptable" behavior. Most Christians oppose such attempts, since Christianity might be considered unacceptable by a non-Christian government.

Significant problems may possibly result from the experimentation necessary for genetic progress. Many poor-quality individuals are created to develop a good plant or animal strain. Similarly, trial and error in human genetic manipulation might produce freaks who would die or live with severe handicaps. Such genetic failures pay for genetic progress by their suffering. Because the Lord values human life, we must be cautious about eugenics. The potential effects of eugenics are great, reaching unborn generations, but Christians cannot condone a eugenic policy that is careless with human life.

One danger of eugenics is that it might lead to the *dehumanization* of man. Man is dehumanized when his essential quality as a living, eternal soul is ignored. Unless eugenics is used carefully, its users may eventually regard man as just another laboratory animal; government may see man as just another "natural resource" to be controlled; and man's spiritual nature may be ignored. Leon Kass stated, "If we come to see ourselves as meat, then meat we shall become."* Since man is created in God's image, he should not be thus degraded.

Dehumanization, though, like government domination and genetic failures, would result from the *abuse*–not merely the use–of eugenics. Those dangers may not arise if genetic research is careful. The reasonable Christian, then, will not

6B-8 *Children are to be trained by parents to love and serve God. Some eugenic practices would hamper this.*

Sonography uses sound to make a picture of the unborn child. (3) A fetoscope is a fiber optic device that can be inserted into the uterus (womb) to view the unborn child.

3. A "test-tube baby" is a fetus that has developed from an ovum that was fertilized outside the female's body and then implanted in the uterus to develop. The term *test-tube baby* is misleading because the baby develops in the uterus, not in a test tube. *Test tube fertilization* and in vitro *fertilization* are better terms to describe what is being done today.
4. The biological mother supplies the ovum of a child. A surrogate mother merely supplies the womb as a place for the ovum of another woman to develop after it is fertilized. Biological mothers may become pregnant, or they may be ovum donors.
5. **(a)** The Genetic Age could produce people who are strong, healthy, and intelligent; it would result in a type of utopia. **(b)** The Genetic Age could result in a "dystopia"; corrupt man could misuse knowledge to form a wicked, oppressive society. People would look to science instead of to God for solutions to their problems.

Answers–Facet 6B-1

1. Recombinant DNA
2. A restriction enzyme "snips" the DNA at a specific base sequence and leaves a "sticky end" which will permit the DNA to combine with other DNA with the complementary "sticky end."
3. Recombinant DNA is DNA that has been cut and put back together with a different piece of DNA put onto the cut ends.
4. The manufacturing of human insulin by a recombinant bacterial plasmid containing the human insulin gene is one example. The implanting of one

oppose the correct use of eugenics but will rather oppose its careless or illegitimate use.

In addition to the dangers discussed above, the Christian should temper his approval of eugenics with one other qualification: disagreement with secular scientists who believe that eugenics will solve all man's problems. They think that the problems have physical causes and thus must have physical solutions. The Bible teaches otherwise: man's suffering is the result of God's curse (Gen. 3:17-19). Eugenics will not establish a perfect race, for God's curse on the earth will prevail until Christ returns (Rom. 8:19-21).

As eugenic research expands, we will have to make difficult judgments about its use. In doing so, we must be sure that our position is in accordance with Biblical principles and is not merely a personal opinion or prejudice. Although we cannot expect the Bible to deal with specific medical or scientific techniques, the Bible does deal with such principles as the value of human life. (See Chapter 24B.) We cannot violate Biblical principles and consider ourselves obedient to God; however, a conclusion based on feeling and not on the Bible is merely an opinion.

The scientific knowledge gained in the "Genetic Age" is just another tool–a very powerful tool–which God seems to be letting man use today. Although this tool may effect God's will as any medical or scientific information can, Christians have the responsibility to use this tool in accordance with God's Word.

Constantly remind the students that a Christian must obey Scriptural principles. No matter how appealing Satan may make an un-Scriptural argument sound, Christians must reject it.

Christians should be concerned about the future. Decisions based on genetic engineering which are now optional may become mandatory if a family is to qualify for medical insurance or federal aid to help the handicapped child. In time the political and spiritual implications may become staggering. Christians must be careful what they permit.

Biological Terms

The Gene Pool and Population Genetics
- gene pool
- variation
- mass selection
- hybridization
- heterosis (hybrid vigor)
- inbreeding
- pure strain

Eugenics
- eugenics
- genetic screening
- ultrasonic scanning (sonography)
- fetoscope
- amniocentesis
- artificial insemination
- biological father
- test-tube fertilization (in vitro fertilization)
- biological mother
- surrogate mother

Facets
- genetic engineering
- recombinant DNA

Review Questions 6B-2

Answers begin on page 165.

1. List three methods of genetic screening and describe each.
2. List and describe three methods currently used to learn about the unborn.
3. What is meant by a test-tube baby? In what way is this term misleading?
4. Differentiate between a biological mother and a surrogate mother.
5. List (a) several reasons the Genetic Age can be considered a desirable dream and (b) several reasons it can be considered a nightmare.

Facet 6B-1: Genetic Engineering, pages 163-64

1. Name one method of genetic engineering used today.
2. Describe what a restriction enzyme does to DNA.
3. What is meant by recombinant DNA?
4. Give and describe an example of genetic engineering.
5. What are some of the potential uses of recombinant DNA?
6. What are some of the possible drawbacks of using recombinant DNA?

Thought Questions

1. Mutations are generally recessive and inbreeding produces individuals homozygous for traits, but what is a possible explanation for some forms of heterosis?
2. A purebred strain of dogs often has weaknesses (poor traits) in some of the offspring, while crossbreeds produce more and healthier pups. Give an explanation for this.
3. "What is called *artificial reproduction* should more accurately be termed *man-assisted* reproduction." Tell whether you agree or disagree with this statement. Support your opinion.

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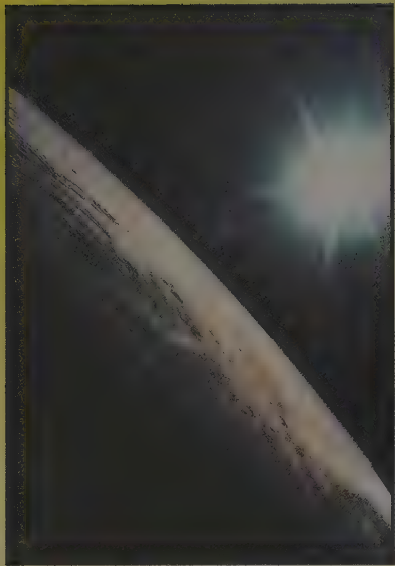
plant's gene into another plant, using a virus as a vector, is another.

5. The transfer of desirable characteristics from one organism to another organism that does not have them is one use. The manufacture of a desired organic substance by bacteria or other organisms is another.
6. Scientists could transfer undesirable or even harmful genes (traits), potentially making a harmless organism into a harmful one.

Answers–Thought Questions

1. Inbreeding may produce homozygous individuals with desirable as well as undesirable traits. Therefore, a heterosis (or hybrid) may be superior in yield and quality because negative, recessive traits would have a better chance of being masked by another allele, as appears to happen in corn and sorghum hybrids.
2. The weaknesses are examples of inbreeding of poor traits (thus resulting in homozygous poor-trait conditions), while the crossbreed progeny are a result of greater selection from a larger gene pool and have less chance for homozygous conditions of poor traits.
3. Most students will agree with this statement. Man is not really carrying on reproduction when it comes to artificial insemination, test tube fertilization, or embryo implants to the biological or surrogate mother. Artificial reproduction will take place when man begins to clone humans by inserting nuclei into ova or rearing babies to birth in a "test tube."



SEVEN

THE HISTORY OF LIFE

Time Frame
7A: 1-1 $\frac{1}{2}$ periods
7B (with Facet): 2-4 periods
7C (with Facets): 2-3 periods

Laboratory Activity
7–*Creationism: My Beliefs and Defense* involves students writing their positions and defending them. This activity can be done orally in class or as homework.

The first paragraph of this chapter is actually a statement of position for creationism against evolution. Go over it carefully with the students. Once it is accepted, all else regarding evolution and creation is merely a logical ramification of this position.

7A–Theories of Evolution

Christians need not wonder about the beginning of life. The beginning of the physical universe is clearly outlined in Genesis 1 and 2. Other Scriptural passages give us additional facts about God's creative act, the history of His physical creation and life, and God's description of what will happen to His creation. Collectively, these passages provide a divinely inspired outline of the history of life. All accurate scientific knowledge, when properly interpreted, fits into this outline. Anything that contradicts this outline is in error.

The first section of this chapter looks at some of what the Word of God says about creation and the history of life. In the next section of this chapter we will consider various interpretations (some acceptable, some unacceptable) of what the Bible says. In the final section we will look at some scientific theories that contradict either the Bible or physical evidence or both.

7–The History of Life

Some of the most difficult material of this survey course is found in Chapter 7. Teaching Biblical creationism and evolutionary theory is not easy. However, an awareness of some common classroom pitfalls will enable teachers to avoid them.

One problem with many well-versed Christian students (who have come from Christian homes and supposedly know a great deal about evolution and creation) is the much-to-be-feared "Amen Syndrome." Students who suffer from this usually recognize the material being taught and busily say, "Amen." In fact, they are so busy agreeing with these points that they forget to learn, study, or master them. The problem is that students become "immune" to certain doctrines and think they know them, but find they cannot produce the information for a test.

The following suggestion can prove disastrous if the teacher is not well prepared, but if it is thoroughly thought out, it can be a great motivator for the sufferers of "Amen Syndrome." Take ten to fifteen minutes of class time (preferably just before the bell) and "play evolutionist." Have the students try to convince you that creationism is the best possible belief, while you argue for the evolutionist's position. If they try the "it has to be accepted by faith" argument, tell them that your faith cannot accept something that is contrary to *all* facts. If they say that "God is revealed in creation," claim that all you see in creation is that God is a liar. He claimed to create, but He obviously did not. At the end, of course, you will need to explain to your students what you are doing, but getting them a little stirred up can be an excellent motivational device.

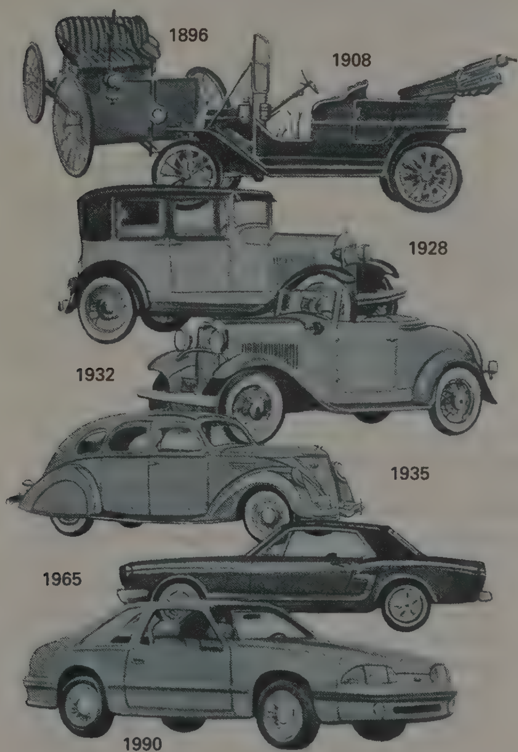
Another problem is the "Eschew Evil Syndrome." Many Christian students will very literally ignore the world and its evil philosophies. Some students feel that they

Evolution conditioning

Some Christians have a serious case of "evolution conditioning." They have heard of the evils of "evolution" for so long that now they cringe and point a finger of condemnation at anyone who even uses the word. The word *evolve,** however, is a good word, meaning "to change, to become more complex."

It is proper, for example, to say that the automobile has evolved. The growing complexity of cars from Henry Ford's models to some of the most recent models is clear. The car, however, did not evolve itself. Rather, human designers and engineers accomplished its evolution. In the same way governments, languages, industry, and most activities in which man engages have evolved.

7A-1 *The evolution of the car*



There is nothing wrong or un-Scriptural about recognizing these progressions as evolutionary.

"Evolution conditioning" affects other Christians when they see pictures of dinosaurs, drawings of strange "prehistoric" plants, or illustrations of half-naked humans with spears chasing odd-looking animals. Many Christians try to ignore them. Other Christians label such pictures "satanic," "atheistic," or "evolutionary."

But, dinosaurs did exist; many plants (very different from the plants of today) are extinct; and even today there are half-naked humans who, armed with spears, chase animals. The evidence to support the past existence of dinosaurs, strange extinct plants, and half-naked, spear-armed men is about as good as the evidence to support the evolution of the car.

The Bible calls Christians the salt of the earth (Matt. 5:13). Salt serves to retard corruption; Christians are to stand against the corruption Satan is spreading and slow down its effects. Two of Satan's best tools for robbing the Christian salt of its savor are to have Christians ignore his activities and to make Christians appear foolish. It is wrong for a Christian to ignore Satan's workings against Christianity. It is also wrong for a Christian to discredit not only himself but also the Lord by making rash, unfounded accusations.

Because Satan has used evolutionary theory effectively against Christians, they should know what they believe concerning this theory. Too many Christians, however, are willing to say, "The Bible is true, and evolution (whatever it is) is false," and leave it at that. The Bible tells us to "be ready always to give . . . a *reason* of the hope that is in [us]" (I Pet. 3:15–emphasis added), not just to *have* "the hope."

Other Christians in a misguided attempt to "be ready" pick up a few ideas, misuse them, and thereby show their ignorance, thus bringing reproach to themselves and their Lord. Christians should know not only what they believe concerning evolution but also what evolution is, before they try to condemn it. We are to "*study* to shew [ourselves] *approved* unto God" (II Tim. 2:15–emphasis added).

evolve: e- (out) + -volve (VOLVERE, to roll)

Give examples of problems caused by Christians who take the shallow positions spoken of in the text.

Today many people define *evolution* as change. This is *not* a definition of evolution but merely an attempt to get a foot in the door. Only a fool would argue there is no change in the world. Admitting that "change = evolution" and that "natural selection can happen" gives the evolutionist all the ammunition he needs to say you accept evolution. It has been done with carefully selected questions similar to "Have you stopped beating your wife?" Evolution, by definition, is *change toward the more complex,* not merely change. Change can be downward or toward less complex, which is not evolution but devolution. A Christian can agree with and even support devolution from Scripture (perfect creation cursed by sin).

need to know only material that is right or Biblical. They ignore all material concerning Darwin, phylogenetic trees, recapitulation, or any other topic they consider evolutionary or "bad." Taking the command to "eschew evil" (I Pet. 3:11), they refuse to learn about anything that seems evolutionary.

This is a difficult situation for the teacher. In asking these students to learn this material, they may perceive they are expected to learn what is evil. Christian teachers do not ask them to *believe* evolutionary theory, merely to *know* what it is. Students need to know what a worldly philosophy is in order to recognize it in its more subtle forms. Satan is subtle. Christians must recognize his basic actions and the far-reaching ramifications of his craftiness in order to stand against him. Convincing some students of this may take work, but it can be done. It is imperative that the teacher not fail his students by allowing them to leave biology class without at least learning to voice what they believe about creationism and evolution and to give reasons for their beliefs.

Lecturing will, of necessity, be the primary teaching technique used in this section. (Successful laboratory exercises and demonstrations of evolution and creation are notoriously difficult to find. To my knowledge, none has ever worked successfully!) However, a creative teacher can employ several other effective methods of presentation. A guided class discussion in which students address a problem and seek possible solutions can be effective.

The four primary points students should gain from this chapter are the following:

- Creationism and evolution do not mix.
- The earth is not billions or even millions of years old.
- Noah's flood is a significant catastrophe, the geological and biological implications of which are usually overlooked.
- The genetic basis of biological evolution is statistically impossible.

Define *evolutionist* and *creationist* as used in this book, and be consistent, or delineate terms like *theistic evolutionist* or *gap theorist.* Warn students to be careful, because in other sources these terms can mean different things.

The three-part division of the broad term *evolution* is relatively easy to understand and works well for the purposes of this text.

The theories of evolution

The **theory of evolution** is a very broad term, encompassing many different concepts. Let us look at some of the major components of evolutionary theory.

❑ **Theory of beginnings** Man's guesses of how the universe, the earth, and even matter and energy came into being are theories of beginnings.

These theories are beyond the scope of this book but are discussed in other books in the Bob Jones University Press science textbook series.

❑ **Theory of biological evolution** *(organic evolution)* Biological evolution deals with the beginning of life (usually by some form of spontaneous generation) and proposes that simple organisms

give rise to more complex organisms, which, in turn, produce even more complex offspring. Biological evolution is at the heart of the various other theories of evolution and will be dealt with in the next sections of this chapter.

❑ **Philosophy of evolution** The idea that all things are progressing toward a future perfection is the philosophy of evolution. This theory teaches that things are currently improving. The evolution of man's knowledge and the evolution of human society are given as examples of this type of evolution. There is, however, good reason to doubt that the increase in complexity (the evolution) of technology, governments, and the like is actually an improvement. What is a good definition of "improvement"? For example, the United States Federal Government has evolved (has become bigger and more complex), but many feel it was better when it was not as big and powerful.

When the term **evolutionist** is used in this book, it refers to a person who believes all three of the above. The term **creationist** will refer to those who believe the Bible is the inspired Word of God and that the Genesis account is a literal description of God's creating the physical universe, life, and man.

Review Questions 7A-1

1. Give two wrong attitudes Christians can have toward evolutionary theories.
2. Why should Christians be informed on evolutionary theories and be able to give Bible-based refutations of these theories?
3. List the three major divisions of the theory of evolution and describe each.

Visual 7A-1 can be used to teach the definitions of evolution and the results of evolutionary philosophy.

The Philosophy of Evolution

The person who carries evolutionary beliefs to their logical conclusion must believe the philosophy of evolution. He might look at how far man has progressed, smile with approving pride, and say, "From chemicals in some prehistoric swamp to a living, thinking, rational being has been a long, slow process. How fortunate things just happened to work out this way. And what about the future? Who knows? Man has come this far; in time he will reach that great perfection toward which he is headed."

When asked about God, an evolutionist may say, "The god-myth was a fine thing that has

If students grasp these major concepts and can back them up with scientific examples and Biblical statements, the Christian teacher's objective is achieved.

7A–Theories of Evolution

Notes–Chapter 7A

This introductory section defines terms and establishes categories. Creationism and evolution are, to most Christian young people, old topics. To motivate their interest in the topic, this chapter seeks to point out the implications of believing evolution. That the logical conclusion of an evolutionary position is humanism and the belief that "God is dead" is news to many young people.

Many Christians want to believe a little evolution (so as not to appear backward) and still keep their faith. This theistic-evolutionary position is untenable. This chapter points out that the Bible is the infallible, inerrant Word of God. All things are sub-

Objectives–Chapter 7A

- ❑ Define and distinguish between the *theory of evolution* and the *philosophy of evolution.*
- ❑ Recognize evolutionary theory as a device of Satan to lead men away from their belief in God.
- ❑ Recognize that one cannot logically accept any part of evolutionary theory without destroying the Biblical concept of God.
- ❑ List several of the logical conclusions of belief in evolutionary theory.
- ❑ Define *scientism* and explain how evolutionary theory supports it.

The Results of an Evolutionary Philosophy

The implications of evolution lead to these dangerous conclusions:

❑ *Man is not responsible to God.* Since man is a product of evolution, he has no creator, he is not responsible to any god, and there are no absolute rights and wrongs. There can be no moral code except that which man sets up and agrees to follow. *Situation ethics* (do whatever seems best in a given situation) and the *new morality* (do whatever you want to do as long as nobody gets hurt) are acceptable.

❑ *Man no longer needs a saviour.* Since there is no right or wrong, and therefore no sin, there can be no punishment; thus, there is no need for a saviour.

❑ *Man's religion should be scientism.* **Scientism** is the worship of science. Rather than calling on God for help, evolutionists look to science to solve man's problems and advance mankind. Evolutionists see science as a method of man's continuing to evolve.

Though few people would state their beliefs in that way, the philosophy of evolution has infected most of modern man's thinking to the extent that unconsciously many men accept these beliefs. The great future that man supposedly is pushing toward and that is promised by evolutionary philosophy is not taught in the Bible. Despite scientific advancement, morality and spirituality are declining in our society and will continue to decline (II Tim. 3:13) until Christ returns for His thousand-year reign on the earth. But even then, God, not man, will bring peace and abundance.

helped us in the past and is still useful for some less intelligent humans. Primitive peoples needed a god-myth to explain their existence and the apparent design and unity of the world around them. Before man had evolved enough to be able to accept the responsibility for what he was, man needed someone else to blame or praise for himself and nature. Some inventive, intelligent men (like Moses, Jesus, Paul, Buddha, and Confucius) invented useful gods and god-systems. The obligation to a creator-controller was used by these leaders to help shape mankind. The concepts of heaven and hell were useful in evolving our society."

Now, however, this evolutionist is ready to pronounce, "God is dead. That is, man no longer needs the concept of God. Since humans now realize that evolution is perfecting man, the concept of obedience to a creator-punisher-rewarder is, in fact, getting in the way. People who believe in these god-myths and in the old-fashioned morals demanded by the god-systems are now standing in the way of 'scientific progress.' "

The results of believing evolutionary theory

Few evolutionists will admit to believing the way that the evolutionist just described does. An evolutionary philosophy, however, leads to such beliefs. Most evolutionists believe parts of the biological evolutionary theory and try to ignore the logical ends of the philosophy of evolution.

A matter of viewpoint

Dr. Bob Jones, Sr., often told the story of two men on a high mountain: one looked at the view and marveled at the wonders God had created; the other looked down and commented that he had never before seen the back of a flying buzzard. What you see is, in good measure, colored by how you look at things.

The interpretation of scientific data can be similarly affected by one's expectations. Looking at a reconstructed skeleton of a large reptile in a museum, a teacher who believes in evolution may say to her class, "Note how large these dinosaurs were. They were believed to have lived during the Mesozoic period, between 70 million and 200

7A-2 *The existence of dinosaur skeletons is hard to deny, but their significance is open to interpretation.*

Carefully discuss the "logical conclusions" to belief in evolution presented in the box. Believing evolution affects not only beliefs about the past but also attitudes toward the present and the future. This makes evolution a crucial issue.

Human genetic engineering (eugenics) as dealt with in the previous chapter is quite logical to a true evolutionist. In fact, based on scientism, eugenics appears to be *the answer* to how to move man toward the "human perfection" for which he is destined without having to wait for mutations to bring about this perfection.

ject to Scripture whether it mentions them directly or as a principle. Science must be subject to the Bible, not the other way around.

Answers–Review Questions 7A-1

1. **(1)** Christians can have the idea that every use of the word *evolve* is evil. **(2)** Christians may ignore the fact that extinct organisms did exist, ignoring the evidence that supports the former presence of these organisms, thinking this evidence is nothing but evolutionary theory.
2. Christians cannot resist the workings of Satan by simply ignoring them. Christians harm the testimony of the Lord through ignorance and rash statements against something they know little about. Since Christians are commanded to be prepared to give an answer for what they believe, they must know not only the ideas behind evolution but also the Scriptural basis for rejecting it.
3. **(1)** The theory of beginnings is man's guess about how the universe, earth, matter, and energy came into being. **(2)** The theory of biological evolution deals with the beginning of life and proposes development from simple to complex. **(3)** The philosophy of evolution is the idea that all things are progressing toward a future perfection: "All things are improving."

theistic: the-, theo-, or theis- (Gk. THEOS, god)

This box should be covered by all students. It presents the unacceptableness of trying to interpret Scripture in light of science. The authority of the Word of God is crucial to all Christian doctrine.

The term **theistic evolution** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Theistic evolution was popular among the Bible scholars around the first of the twentieth century and has left a long trail of problems for fundamentalist Christians. Any position that places the Bible under the authority of anything else, including science or supposed scientific facts, is compromise and must be ardently condemned. Compare this to Galileo's dealing with the Roman Catholic Church (see p. 650). The "sides" one takes may make for strange bedfellows. The goal is to get students to think about their beliefs and the true place of Scripture and science.

Many Christians unconsciously accept some of the tenets of evolution and deny others. It is all or nothing. One must believe all the Word of God or believe none of it. To accept what seems good is "having a form of godliness, but denying the power thereof" (II Tim. 3:5).

million years ago. Dinosaurs probably became extinct 70 million years ago."

Looking at the same skeleton, a teacher who believes in creation might say to her class, "Note how large these dinosaurs were. They were believed to have lived prior to Noah's Flood, which many Bible scholars agree occurred about 6,000 years ago. Dinosaurs probably became extinct at the time of the Flood."

Both teachers are telling what they believe to be the truth about the dinosaur skeleton. They cannot both be right. The different interpretations result from different viewpoints.

Explaining the earth's origin and development by looking at the earth is scientifically impossible. Recall that science is the observation of the physical universe. The origin of the physical universe was not observed by human eyes, nor can men go into a laboratory and create a universe to see how our universe might have originated. The beginning of the world and of life and the past changes in them are actually beyond the scope of science. What a person believes about these things is not the result of scientific facts but of *faith*. One will naturally interpret scientific data according to his faith.

For example, it has been adequately demonstrated that life does not spontaneously generate in today's world. Creationists believe that this is good evidence for the necessity of a Creator. Evolutionists, however, claim that conditions were somehow different when life *did* spontaneously generate. They thus keep looking for the right conditions in their experiments in the laboratory. How one interprets the fact that spontaneous generation does not now happen naturally is a matter of viewpoint. No matter which position a person accepts, he believes it by *faith*. Science cannot help him decide because the beginning of life is beyond the scope of science.

Evolutionary beliefs and the Word of God

For about a hundred years, most scientists and educators have presented the theory of biological evolution as fact–a dishonest, unscientific thing to do. A hundred years ago the scientific facts available could have made an evolutionary inter-

Theistic Evolution

Some people, thinking that a person can believe in parts of the evolutionary theory and the Bible, try to mix the two beliefs. This mixture is called **theistic*** (thee IS tik) **evolution.** A theistic evolutionist tries to interpret Biblical statements in order to support evolution. The Bible teaches that God created by direct act. A person who believes that God directed evolutionary processes is a theistic evolutionist and is in error. When the Bible states one thing and, in an attempt to be scientific, a person believes something else, he is setting up scientific theory as more authoritative than the Word of God.

The Bible is the cornerstone of Christian faith. If the Bible is fallible, if it must be amended to conform to scientific theory or man's beliefs, then Christians are without hope. People who do not believe the Bible is the inerrant Word of God choose what parts they want to believe and ignore those passages they do not want to believe.

If it is permissible to disbelieve the Biblical account of creation, then one might disbelieve other parts as well. He might dismiss God's condemnation of sin and the need of the atonement of Christ's blood because these doctrines do not appeal to him. A person who rejects any portion of the Bible has placed himself above the Bible. The Bible is accurate in *everything,* or it may as well be accurate in nothing.

Christians who try to accept evolutionary theory when the Bible clearly teaches creationism are saying that a section of the Bible is not true. The question of whether the Bible or human speculation is true then becomes a matter of choice, open for debate.

Dr. Bob Jones, Sr., has rightly said, "Whatever the Bible says is so. Whatever man says may or may not be so." This is the *only* consistent Christian position. All scientific facts and the interpretation of those facts, therefore, must fit into the model prescribed by the Word of God. A scientific "fact" that does not fit into the model outlined in the Bible is either in error (and therefore not really a fact) or is being misinterpreted.

Answers–Review Questions 7A-2

1. An evolutionist acknowledges only a "god-myth" which satisfied the curiosity of primitive people who desired to understand their beginnings and the existence of the earth. These people of lower intelligence used a god as someone to praise or blame until they themselves had evolved enough to accept responsibility for what they were. Now the evolutionist proclaims that "God is dead"; man no longer needs the concept of a higher being.

*2. **(1)** Man is not responsible to God. **(2)** Man does not need a Saviour. **(3)** Man's religion should be scientism.

3. Both claims are based on faith because man cannot scientifically prove how the world was created.

4. An evolutionist can view a particular fossil and relate its age and characteristics to evolutionary time periods and developments. A creationist viewing this same specimen would relate it to the time period that would be consistent with the Word of God and the creationist viewpoint.

*5. Theistic evolution permits people to pick and choose what they want from science and from Scripture. Thus, those parts of the Bible which are offensive or harsh can be rejected. Theistic evo-

pretation *seem* possible. Today, however, many more facts are available, and if these facts are examined thoroughly and honestly, an evolutionary interpretation simply does not fit them.

This is true of all science: accurate observations do not contradict God's Word. All the "proofs" from observations that have been set forth against the Bible are inconclusive for two reasons.

- Scientists cannot really *prove;* they can only observe and interpret their observations. (Their interpretations are, of course, affected by their viewpoint.)
- Any accurate observation of God's creation could not contradict the revealed Word of God. The Christian's faith can be strengthened by the fact that true science never has contradicted the Bible, and the Christian's faith assures him that it never will.

In many groups it is considered unintellectual to disagree with evolution. Many scientists therefore remain silent about their doubts and dissatisfactions with the theory. Some of them, however, are beginning to say that current evolutionary views are unacceptable and need to be reworked, but they have not yet produced a replacement they consider acceptable. Although most of them choose to ignore creationism as an alternative, a few are convinced that the Bible's statement of creation is the best and only explanation of man's origin.

The Bible does say certain things about creation. But since the Bible is a spiritual handbook and not a scientific textbook, it does not contain all the details of creation or biological history since creation. Many current scientific observations, therefore, are open to various interpretations. We can be sure, though, that anything that contradicts the Word of God is wrong. You should be tolerant of other Christians who believe theories different from yours unless their theories are un-Scriptural.

In this chapter we will discuss the theories of creation and biological history held by most Christian scholars who believe in the infallibility of the Bible, and then we will briefly discuss many of the beliefs of evolutionists. Complete documentations of all these theories and coverage of all the possible ramifications of the material presented in the next few pages is beyond the scope of a high school survey textbook. For those who are interested in more detailed information on the creationist viewpoints described here, write to Bob Jones University Press.

The bias mentioned in Chapter 1, which is a limitation of science, is illustrated here. What a person believes determines how he interprets facts.

Consider reviewing some of the material in Chapter 1A (especially pp. 16-18, 25, 27-29).

When studying the problems of evolution, students often ask, "Don't scientists see this? If so, then why are they still evolutionists?" Many scientists accept the bias of their predecessors, teachers, or superiors and dismiss the question. Others fall into the group described here.

Encourage students to let the Word of God be the final judging point. Listening to good men and getting their opinions is good, but Christians are told in Scripture to hold everything up to the light of the Word of God.

Biological Terms

evolution, theory of	philosophy of evolution	*The Philosophy of Evolution*
beginnings, theory of	evolutionist	scientism
biological (organic) evolution, theory of	creationist	theistic evolution

Review Questions 7A-2

1. How would a person who believes in the philosophy of evolution describe God?
2. List three results of believing in the philosophy of evolution.
3. On what basis are the claims of both evolutionists and creationists accepted?
4. Give an example of how a different viewpoint can cause two people to draw different conclusions from the same data.
5. Give several reasons that theistic evolution would appeal to some people.
6. Why is theistic evolution not acceptable to Bible-believing Christians?

Thought Questions

1. Compile a list of the basic beliefs of the theory of evolution. Compile a list of Scripture verses that could be used to show the fallacy of each of these beliefs.
2. Compile a list of modern beliefs, practices, or activities that reflect the philosophy of evolution rather than a Biblical philosophy.
3. Compile a list of Scripture verses that you could use to show a Christian who is a theistic evolutionist the error of his belief.

lution appeals to some people because it permits them to appear scientific while retaining a semblance of Christianity.

*6. The Word of God must be infallible and inerrant, or a Christian's faith is groundless. If Scripture is subject to man rather than man subject to Scripture, Scripture is useless.

*From a box

Answers–Thought Questions

1. **(1)** Living things change with time; the genetic make-up of a population changes; see the "after their [its] kind" lists in Genesis 1:11-12, 21, 24-25. **(2)** New species are produced by natural selection; see I Corinthians 15:39. **(3)** "Common ancestors" give rise to a variety of different organisms (e.g., an ape-man was the common ancestor for apes, monkeys, and humans); Matthew 19:4 refers to the special creation of humans.
2. **(1)** Communism applies survival of the fittest, suppressing freedom of personal rights. **(2)** The United Nation's influence promotes a one-world government. **(3)** The ecumenical movement endorses humanism as the world religion. **(4)** Environmental control is overemphasized even at the expense of national security.
3. **(1)** (Gen. 1:9-19) Plants created first, then the sun; time period must have been short. **(2)** (Gen. 1:31) Creation completed in twenty-four-hour periods. **(3)** (Gen. 2:7) Specific creation of man. **(4)** (I Cor. 11:8, I Tim. 2:13) Creation of female completely unlike male or animals. **(5)** (I Cor. 15:39) Man is unique.

What does the Bible actually have to say about creation and the history of living things? Some Christians seem to know more about what the Bible does not say on the subject than what it does say. They realize facts such as, "Dinosaurs are not mentioned in the Bible," and "The Bible does not explain where Cain got his wife." Instead of concentrating on what the Bible does not say, let us focus on what the Bible *does* say about creation and history. We can learn much from what the Bible says and from what we are able to observe of the present physical world.

Both the long-day theory and the gap theory are examples of models which are not set forth in Scripture but do not directly contradict it.

Scripture lends only tenuous support to "long days." Twenty-four-hour days are probably better supported from Scripture. If one chooses to accept the long-day theory, he may do so. However, if he does so to support his belief in biological evolution (he uses the time to permit evolution to take place), he is believing in the long days for an un-Scriptural reason.

A person can also believe the gap theory if he chooses, even though Scripture does not support it with any direct statement. His reasoning must be condemned, however, if he believes in the gap theory to provide time for evolution to take place. Using the gap as a time for dinosaurs and the like is to ignore the significance of the Flood (see pp. 176, 178-84). The discussion on pages 413-15 also indicates that dinosaurs were probably not part of a pre-gap creation but rather a part of the antediluvian world with a possible few survivors in today's world.

Creation week: long or short days

Review the sequence of events in the creation week as outlined in figure 7B-1, and read the account of the creation as described in Genesis 1 and 2. Some people argue that this sequence of events is scientifically impossible. Noting, for example, that plants were created before the sun, moon, and stars they ask how plants could have lived without the sun. Light, though, was created on the first day but simply had not been organized into the sun, moon, and stars as we know them.

Creation is in itself scientifically unexplainable. Knowing why or how God created things the way He did is not only beyond the scope of science (for it cannot be observed) but also beyond the comprehension of human minds (Job 38-40:5).

Some Christians interpret the seven days in Genesis 1 as seven ages. This interpretation is sometimes called the **long-day theory (day-age theory).*** Second Peter 3:8 ("One day is with the Lord as a thousand years, and a thousand years as one day") is often cited as support for the long-day theory. This passage, however, simply teaches that God is eternal and timeless.

Most people who hold to the long-day theory are attempting to put enough time in the Genesis account of creation for evolution to take place. This is an attempt to prove that God *directed or permitted* the evolution of the universe rather than actually created it as He did. If God says He created the world in six days and man refuses to believe it, then man is calling God a liar.

Some Bible-believing Christians believe in the long-day theory. It does not directly contradict Scripture; but a person who believes in the long-day theory for the purpose of appearing more "scientific" is a theistic evolutionist, and his motive is unacceptable.

Other Christians believe that the days in Genesis 1 are 24-hr. periods. This belief is the **short-day theory.** The short-day theory is supported by the phrase "the evening and the morning," repeated often in Genesis, and by the fact that the sequence of events described requires speed. For example, many plants (if they were like today's plants) can live for only a limited period of time without organized day, night, and seasons, and without animals to pollinate them.

The gap theory

According to the **gap theory** there was a long period of time between Genesis 1:1 and 1:2. (Some people place the "gap" even before verse 1.) Gap theorists believe there was a "first creation" which was destroyed, probably (they say) by the fall of Satan described in Isaiah 14:12-17. This period ("first creation" and "gap") may have been thousands, millions, or even billions of years long. The gap theory first appeared in writing about A.D. 400, but it did not become popular until about a century ago when evolutionists began to claim the earth was hundreds of thousands to millions or even billions of years old. The gap theory allowed Christians to accept the evolutionists' "old earth" yet not detract from the creation account in Genesis.

To use the gap theory to harmonize evolutionary theory and the Bible is to misuse it. To say that the first creation is recorded in the fossils, and that the geologic ages evolutionists speak of happened during the first creation is to ignore strong scientific evidence (which will be discussed later in this chapter) and several Biblical implications (see page 176).

The gap theory does not directly contradict Scripture, but it is not the only theory of creation and biological history that fits into the Biblical framework. In reality, the best creationist theories

7B-Biblical Creationism

Notes-Chapter 7B

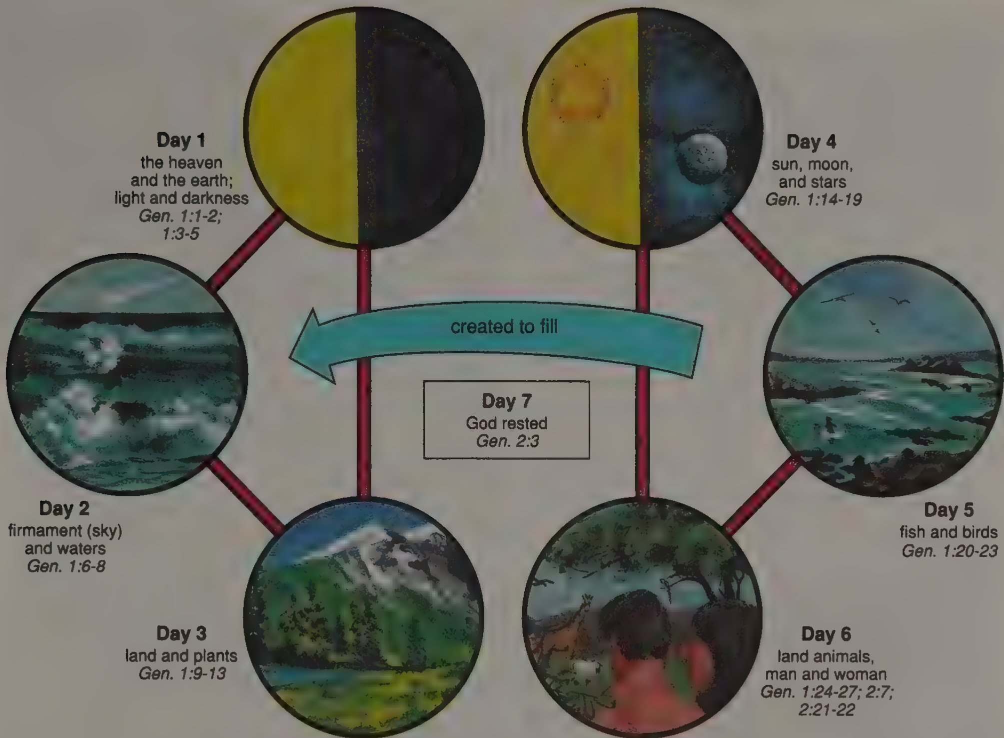
Many Christians say they are antievolution and pro-Bible. They are willing to say the Bible is *right*, without knowing what *right* truly is. They have no understanding of how the "rightness" of the Bible affects them.

The first step in taking any position is to know what the Bible says and then to apply it to modern situations. That is the goal of this chapter. For many students this will be their first look at the evolution-creation controversy in anything other than an antievolution framework. The students will learn what the Bible says regarding creation in more depth than a typical Sunday school presentation of Adam and Eve.

Some Christians object to the concept of creationistic *theories*, saying that creation is *fact*, not theory. True, creation is fact. Details of creation, however, are not given by God. Details and the ramifications of those details are theories–theories developed from the facts given by God–but theories nonetheless. One could argue that a theory based on Scripture is better than a theory based on observation; however, the theories presented here (e.g., long day, short day, gap, nongap) are based more on interpretations of Scripture than on actual Scripture.

The material about the gap theory and the long- and short-day theories may require careful attention to avoid offending parents and other interested parties. It is best not to inject personal beliefs and exclude all other possibilities. Go back to the Bible; what it says is so, and what it does not say is open to speculation.

This text attempts to present, clearly and fairly, on a high school level, the tenets of all major Biblical positions. This should permit students to see the problems and strengths of the various positions, no matter which they personally adopt. It is, of



7B-1 *The days of creation can be illustrated using the above diagram. The materials created on days 1-3* (left) *correspond to the materials created on days 4-6* (right).

antediluvian: ante- (L. ANTE, before) + -diluvian (DILUERE, to dilute)

The Days of Creation pictures in poster form are available from the Bob Jones University Press and can be used for bulletin boards or other teaching aids.

are those that harmonize the literal Biblical account and scientific evidence.

The canopy theory

The Bible tells very little of the **antediluvian*** (AN tih duh LOO vee un) (before the Flood) earth. However, it was similar to the earth in which we now live. There were seas, rivers, and mountains (Gen. 1:10, 2:10, 7:20), as well as animal and plant life, before the Noahic Flood.

The Bible also implies differences. Many Bible scholars agree that there was no rainfall before the Flood, plants being watered by mist which rose from the earth (Gen. 2:5-6). Second Peter 3:6-7 says that "the world that then was, being overflowed with water, perished: but the heavens and the earth, which are now . . . are kept in store." Apparently, "The world that then was" (before the Flood) differed from "the heavens and the earth which are now" (after the Flood).

One of the major differences mentioned in Scripture and implied by scientific evidence is the existence of a layer of water vapor around the antediluvian earth. Genesis 1:6-8; 7:11; 8:2 and II Peter 3:5-6 attest to this God-created canopy of water above the earth. The water vapor composing this layer would probably have been considerably higher and more abundant than the water vapor now in our clouds.

This canopy of water is believed to have fallen when "the windows of heaven were opened" (Gen. 7:11) at the time of Noah's Flood. The layer of water vapor must have been a transparent layer, not obscuring the sun, moon, and stars but probably affecting the radiation of the sun on the earth.

The canopy theory is not a doctrine either. Scripture speaks of water above the earth, but the quantity and its effects are theory. This theory, however, is not contradicted by any Scripture and is supported by logic as well as good scientific indications.

Objectives–Chapter 7B

- ❑ Differentiate between and give Biblical support for the long-day theory and the short-day theory and for the gap theory and the non-gap theory.
- ❑ Produce a Biblical timetable for major past events.
- ❑ Recognize the geological timetable as a manmade, evolutionary interpretation of a natural phenomenon.
- ❑ List several logical reasons for believing that the Genesis flood was universal.
- ❑ Describe several methods of fossilization and discuss their natural occurrence in today's world.
- ❑ Describe the flood theory of fossil formation.
- *❑ Describe Noah's ark and account for the animals on it.
- ❑ List the three main reasons evolutionists use to justify the old-earth theory.
- ❑ Describe several of the radiometric dating methods and show the fallacies of some of their logic.
- ❑ Understand the limitations of dating methods using carbon-14 and other compositional substances.
- ❑ Define, explain, and give examples of *apparent age, half-life, polystrate fossil, glaciation,* and *topography.*

*From a Facet.

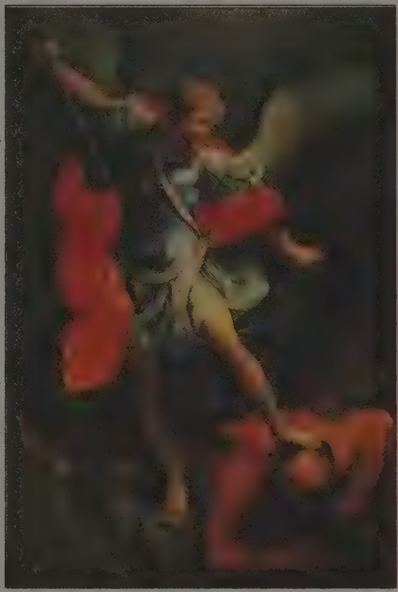
Go over the Scripture references discussed in this box, pointing out the tentative nature of the gap theory support. The gap theory is not a doctrine nor a principle of Scripture. It is wise for students to see that people can use the Bible to support something which may not be accurate. Christians must "try the spirits to see if they be of God" and not accept something just because someone *says* it is Biblical.

Scripture and the Gap Theory

Biblical Arguments Against the Gap Theory

❑ *The time of Satan's fall* According to many Bible scholars, Isaiah 14:12-15 and Ezekiel 28:12-19 speak of the wicked, earthly kings of Tyre and Babylon and also describe the fall of the ultimate ruler of wickedness, Satan. According to those who believe the gap theory, the fall of Satan described in these passages fits into the gap and explains why the earth was formless and void. Those who do not believe the gap theory believe that the fall of Satan fits better into the period between Genesis 2:25 and 3:1. The clause that "God saw every thing that he had made, and, behold, it was very good" (Gen. 1:31) does not leave much room for Satan and sin on the earth at that time.

❑ *The results of Satan's fall* If the earth had been destroyed by Satan's fall and *became* "without form and void" (Gen. 1:2), there would be no trace left of a previous creation–certainly not the layers of fossils we find today.



Michael Overcoming Satan by Giovanni Andrea Sirani. Bob Jones University Collection of Sacred Art.

Satan was cast out of heaven and will be cast into the bottomless pit. The times of these events have been debated by scholars for centuries.

❑ *The time of the first sin and death* Romans 5:12 says that "by one man sin entered into the world, and death by sin . . ." This seems to indicate that there was no death until Adam's sin. A "first creation" destroyed, as gap theorists speculate, would apparently contradict this passage.

For their sin Adam and Eve were expelled from Eden.

Biblical Passages Supporting the Gap Theory with Arguments Against Them

❑ *Genesis 1:2* Gap theorists translate the first part of the verse with the word *became* instead of *was:* "And the earth *became* without form and void." Opponents are quick to point out that *was* is the more common meaning of the Hebrew word in sentences like Genesis 1:2.

❑ *Genesis 1:2* The phrase "without form and void" appears in one other Bible passage, Jeremiah 4:23, which speaks of God's judgment. Some gap theorists therefore conclude that Genesis 1:2 also deals with judgment, and they tie the judgment of Satan into Genesis 1. Opponents hold that only the context of Jeremiah 4–not the particular phrase–relates to judgment. "Without form and void" is a neutral phrase.

❑ *Genesis 1:28* Gap theorists observe that the word *replenish* implies refilling or repopulating. Only if the world had been previously filled could man "replenish the earth." Opponents point out, however, that the Hebrew word translated "replenish" can also be translated simply "fill."

❑ *Isaiah 45:18* This passage, a testimony of God's creative power, states that God "created [the earth] not in vain, he formed it to be inhabited." The word translated *in vain* in this passage is the same word used for *without form* in Genesis 1:2, and some gap theorists therefore tie the two passages together. The preceding verse in Isaiah, however, speaks of God's saving Israel. God created the world to be inhabited, not formless, and He accomplished that purpose by filling the earth with creatures. The same power which accomplished this *will* accomplish God's saving Israel. God created the world intending to fill it, just as He called Israel intending to save her.

course, quite possible to be a born-again, Bible-believing Christian and not hold one position exclusively.

The second part of this chapter deals with the age of the earth based on Scripture (which does not give details) and on science (observations). The scientific method cannot be trusted because of the unknowns involved in any form of scientific dating. One can easily become bogged down in the details and examples of this section. The purpose is to throw reasonable doubt on the scientific dating methods and to point out that Scripture sets a framework but does not give an exact age of the earth. God does not tell man exactly when Adam was created, but scholars have some good theories based on Scripture.

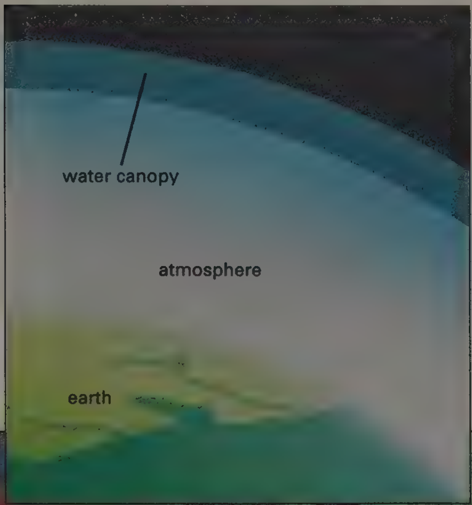
The box dealing with radiocarbon dating can be confusing. The arguments against the method are the same basic arguments discussed in the chapter regarding the radiometric dating method. The details, however, are different, and since radiocarbon dating is the most common and "reliable" method, it is discussed separately.

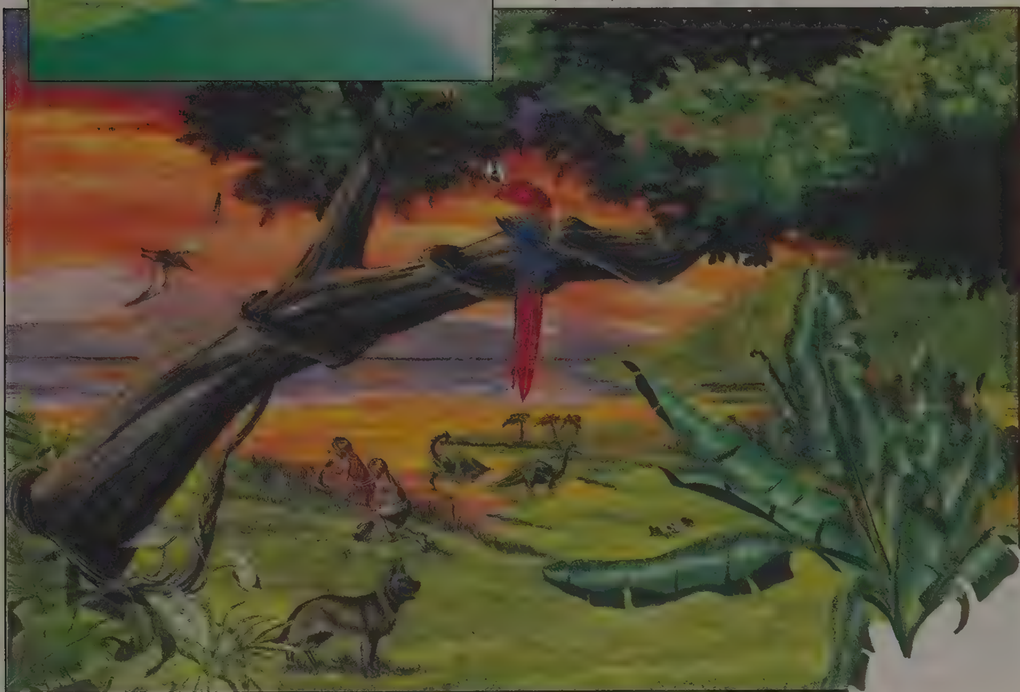
Facet–Chapter 7B

The Facet is an interesting sidelight, and just reading it will answer most students' questions about Noah's ark. Very little class time should be spent on it.

According to this **canopy theory,** antediluvian weather was different from present weather. Because of the thick water vapor layer, a uniformly warm climate with higher humidity existed. This *greenhouse effect* would make conditions over almost all the earth similar to those in the tropics. These conditions would have been ideal for the many large plants and animals (like large dinosaurs and giant insects) that left abundant fossil deposits but are believed to be extinct today. Such organisms would find few, if any, places today with environments suitable for them.

The existence of water above the antediluvian earth is a Biblical fact, but the idea of a water vapor canopy and its effects is theory. Differences between the antediluvian and the *postdiluvian** worlds can be explained by the canopy theory. In harmony with Scripture and many observable features of our current world, many Christians consider it a good theory.





7B-2 *The water canopy above the earth* (left) *would have caused a greenhouse effect. Many creationists believe that the antediluvian human civilization and the organisms we now find as fossils coexisted (below).*

postdiluvian: post- (L. POST, after) + -diluvian (to dilute)

Today ozone forms a protective canopy over the earth. Loss of the ozone layer could result in effects as devastating to life as the loss of the water canopy at the time of the Flood. Such effects are only speculation and may not actually happen. Carbon dioxide appears to be forming a layer (type of canopy) speculated to cause a greenhouse effect that could drastically change the earth.

Consider the significance of this illustration: cultivation, metal work (tools), domesticated animals, plants and animals similar to ones on earth today, and some thought to be extinct.

fossil: (L. FOSSILIS, dug up)

Scripture does not state that there were no rainbows before the Flood. This is assumed. God may merely have taken a physical phenomenon with which Noah was familiar and given it special significance.

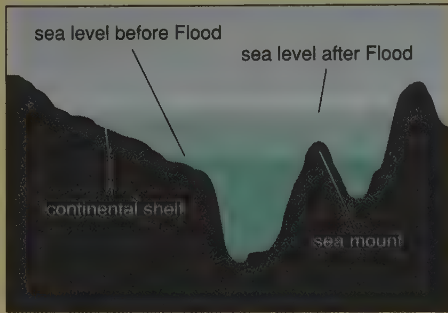
Supposedly, mutations increase with more exposure to the sun's radiation, which increases the genetic load of a species. Thus the life span could be expected to drop. Although logical, this is speculation.

Other Indications of the Canopy Theory

❑ *The sign of the rainbow* The sign God gave to Noah that there would never be another universal Flood was the rainbow (Gen. 9:12-17). If conditions had been the same before the Flood as they are now, rainbows would have been common before the Flood. The canopy, however, could help account for the absence of rainbows before the Flood.

❑ *The length of human life before the Flood* The average human life span before the Flood (based on Genesis) was 912 yr. After Noah the life span quickly dropped to about 400 yr.and continued to decline. Abraham, Isaac, and Jacob lived well over 100 yr., but few men after their time have reached even 100 yr. Many Bible scholars consider this decrease in life span to be a result of sin. A cause for this decrease could be the loss of the filtering effect of the canopy resulting in direct exposure to solar radiation.

Adam	930	THE FLOOD	Eber	464
Seth	912		Abraham	175
Jared	960		Moses	120
Methuselah	969		PSALM 9:10 – 70 years	
Noah	950			



❑ *The continental shelves and seamounts* The shelves of land around the continents, as well as many mountains in the sea, appear to have been dry land at one time. They would have been above sea level before the Flood with the large quantity of water believed to have composed the canopy now on the earth.

Review Questions 7B-1

1. List what was created on each day of the creation week.
2. List several reasons for believing in (a) the short-day theory and (b) the long-day theory of creation.
3. List several arguments for and against the gap theory.
4. Describe the canopy theory, and list several reasons it is considered a Scripturally and scientifically acceptable theory.

Evolutionists believe that fossilization is an ongoing process. This is false, as analysis of these major fossilization methods can account. Two basic concepts for students to grasp are the following: (1) Fossils are not being made in large quantities today, and (2) only under vastly different conditions (like a catastrophe) would an abundance of fossils be formed.

Fossils and Noah's Flood

A **fossil*** is any direct or indirect evidence of a once-living organism. A dead body or a footprint can therefore be considered a fossil. A dead body usually decomposes quickly; and a footprint, unless made in cement or some similar material, is also temporary. However, the term fossil normally refers to remains of long-dead organisms which have been naturally preserved.

Fossilization

Fossilization (the forming of fossils) is not naturally happening to any appreciable extent today. When an organism dies now, it is only a matter of time before it decomposes, leaving no trace that it existed. Scientists can only theorize about how the fossils we find so abundantly were made.

Let us look at some of the types of fossils and some considerations of how these fossils were formed.

❑ *Preservation of parts* The most abundant type of fossils is the preserved hard parts of animals (bones, teeth, shells) and plants (stems, seeds). These often lie in vast layers, sometimes hundreds of square miles long and many feet thick. In some

Answers–Review Questions 7B-1

1. **(1)** Day One–light and darkness, day and night; **(2)** Day Two–firmament, waters divided; **(3)** Day Three–dry land and seas, plants; **(4)** Day Four–sun, moon, stars; **(5)** Day Five–animals of air and water; **(6)** Day Six–land animals, man
2. **(a)** The short-day theory is supported by the phrase "the evening and the morning were the first day"; also, the sequence of events requires short time periods (e.g., plants can live only a short time without organized day and night and without animals to pollinate them). **(b)** The long-day theory claims the phrase "One day is with the Lord as a thousand years" and attempts to prove that God directed the evolution of the world. This theory appears more "scientific."

*3. For: **(1)** The fall of Satan fits into this gap and explains why the earth was formless and void. **(2)** Genesis 1:2 may be translated "became without form and void." **(3)** "Without form and void" appears in other passages related to God's judgment; thus this can be associated with the judgment of Satan. **(4)** Since "replenish" (Gen. 1:28) implies refilling, the earth had to have had life previously. **(5)** "In vain" in Isaiah 45:18 is related to "without" in Genesis 1:2, saying that God did not create the world without form, which implies a first creation.
Against: **(1)** Genesis 1:31, which states that God saw that everything was good, was prior to Satan's fall to earth. **(2)** Destruction of a first creation would have destroyed the fossils. **(3)** The first sin and death were Adam's; a previous destruction of the earth would contradict this. **(4)** Hebrew meanings for words in Genesis 1:2, 28 and Isaiah 45:18 taken by gap theorists to prove their theory actually disprove the gap

areas even the soft parts have been so well preserved that scientists can determine types of chlorophyll, contents of stomachs, and shapes of muscles. Today when something dies, even its hard parts will usually deteriorate within a few months. In order for its hard parts to fossilize, an organism must have been *quickly* placed under pressure in rock forming sediment. This type of fossil is not formed naturally today.

❑ *Preservation of carbon (coal)* Coal is believed to be a massive collection of mostly plant material which was placed under great pressure. Experiments have shown that under proper conditions plant material can form coal in 20 min. It is estimated that to form a vein of coal 40 ft. thick over 200 ft. of green plant material must be compressed. Although plant material does collect in the bottoms of swamps and bogs, conditions do not now exist for the natural formation of coal in such places. No coal is known to be naturally forming today.

❑ *Preservation of forms (casts or molds)* Casts or molds of organism's bodies are believed to have formed when the organisms were placed in a substance which quickly (before the body could decompose) formed into stone. When the surrounding substance had solidified enough to hold its form and the body of the organism dissolved away, an empty or fluid-filled form was left. This type of fossilization may occur today (though rarely) in tar pits. But no extensive casts or molds are now forming in sedimentary rock.

❑ *Preservation of tracks* Scientists have found extensive areas of preserved animal tracks, usually rock that was once clay or mud. Tracks of large reptiles and various other extinct animals are numerous, and in some cases human footprints can be found in rock. Materials were apparently laid quickly into the tracks to aid their turning to stone before they had a chance to be destroyed. Today footprints made in clay or mud are soon gone.

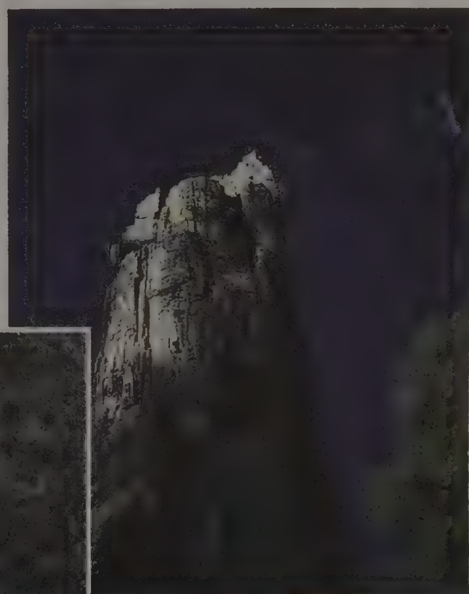
❑ *Petrification* Usually only the hard parts of an organism are petrified. Petrification seems to happen when water containing dissolved minerals penetrates into the structure. The water then somehow leaves, and the minerals remain, collecting within the spaces of the structure and eventually turning them to stone. Extensive petrification is apparently not happening today. Organisms normally rot underwater.

❑ *Freezing* In Siberia and Alaska large numbers of animals have been found frozen fast. Best known are the mammals that froze so quickly they still had food in their mouths and were in such

7B-3 *Various kinds of fossils*

Preservation of parts

A dinosaur track



A petrified tree stump

Coal can be formed quickly with laboratory conditions of high temperature and pressure.

How these animals were frozen so quickly is not known. Temperatures much lower than even those at which they were found would be required to freeze the larger animals so quickly. Some have suggested that an explosion threw these organisms into the upper layers of the atmosphere where the extremely cold temperature fast-froze them. This explanation is weak in several points: what kind of explosion sends organisms that high without destroying them? If they fell that far and were frozen solid, why were they not shattered on impact?

theory or can have meanings other than what the gap theorists would propose.

4. A thick layer of water vapor surrounded the earth and was probably higher and more abundant than water vapor in clouds today. This transparent layer blocked harmful radiation from the sun but did not block out light. It created a greenhouse effect ideal for preserving life and allowing growth of large plants and animals. Reasons for accepting it are (1) the existence of fossils of organisms which possibly could have survived only under conditions described in the canopy theory; (2) the rainbow signified a change in atmospheric conditions; (3) life spans were longer before the Flood, probably because of the ideal conditions created by the vapor canopy; (4) the continental shelves and sea mounts appear to have been dry land at one time. They would have been above sea level before the Flood, when large quantities of water would have been in the canopy rather than in the oceans.

*From a box.

deluge: de- (from) + -luge (L. LAVERE, to wash)

sedimentation: (L. SEDIMENTUM, the act of settling)

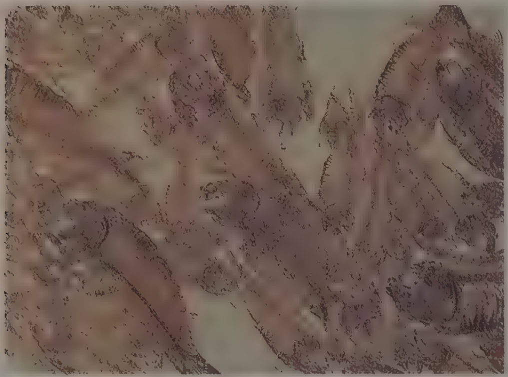
Point out these reasons for believing in the deluge fossil formation theory. Students should learn and understand these reasons.

good condition that they have been fed to dogs. Today animals are not being permanently frozen in any quantity. The quick freezing of such large animals (many of which are not arctic) suggests some major catastrophe.

Fossils formed by other methods are rare, limited, or unidentifiable.

The deluge and the fossilization

To consider the **deluge*** (DEL yooj) or Noah's Flood (see Gen. 6-9) a local flood is to contradict Scripture. In the box on the right are seven reasons why the deluge must have been a *universal flood* (covering the entire earth). The effects of such a flood are open to considerable speculation. Various theories have come into existence.



7B-4 *Fossil fish. Fossils are frequently found in masses, an indication of a catastrophe.*

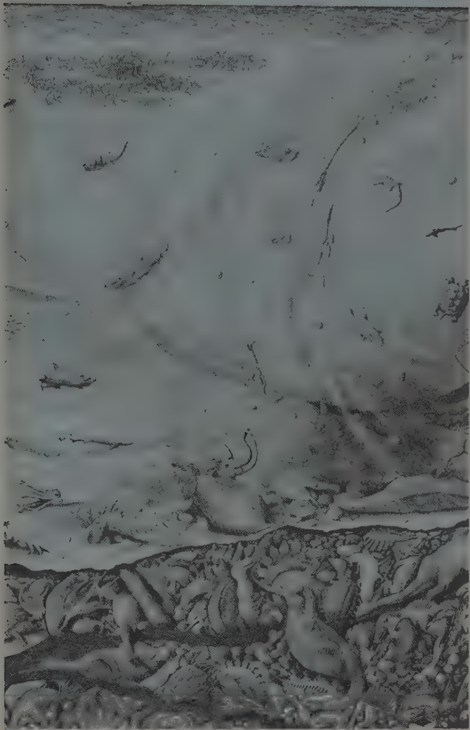
The **deluge fossil formation theory** is held by many Christian scholars. Until about a century ago most written material–Christian and non-Christian–indicated that the fossils were formed by the deluge. In the 1800s, however, evolutionists began to suggest that the fossils were a *progressive record* of past times and had taken many thousands, millions, and even billions of years to form. The concept of fossils being formed by various methods over long periods of time was an attempt to support evolutionary theory. Today, however, some research and experimentation is producing support for the deluge fossil formation theory.

An entire earth covered with water, as in the deluge, would contain many strong currents, possibly even stronger than the major currents found in our oceans today. Recall that the purpose of the Flood was to destroy the world. The Flood currents would therefore be strong enough to carry any material on the face of the earth which could be moved.

As the currents slowed down or changed course during the deluge, they would have deposited the materials they carried. This **sedimentation*** (settling out of materials) accounts for the layers of **sedimentary rock** which contain most of the fossils and compose most of the *topography* (tuh

Reasons the Deluge Was Universal

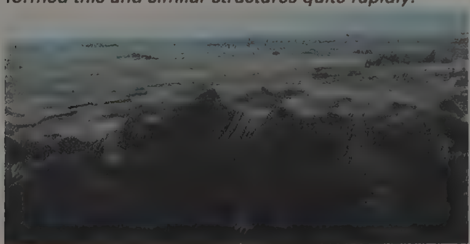
1. The purpose of the deluge was to destroy all flesh except that which was in the ark (Genesis 6:13, 17; 7:4, 19-23). This could not have been done if the Flood had been local, since people as well as animals could have migrated outside the area of a local flood.
2. The waters covered the highest mountains to a depth of over 20 ft. (Genesis 7:19, 20; 8:5). Since water seeks its own level, to cover a mountain by this depth requires a universal flood.
3. The duration of the Flood was over a year. Local floods do not last that long.
4. An ark to preserve Noah, his family, and the animals was unnecessary if the Flood were local.
   - The time (over 100 yr.) spent building the ark was wasted if the Flood were local.
   - The raven and the dove would have been able to find places to rest if the Flood had been local.
   - There would have been no need to take most animals into the ark if the Flood had been local.
   - The prescribed size of the ark was unnecessary if the Flood were local.
5. God made a covenant with Noah that there would never again be such a flood. The rainbow symbolizes His promise (Genesis 8:21; 9:11, 15). The covenant has been repeatedly broken if it referred to local flooding.
6. The testimony of Christ (Luke 17:27) is that all were destroyed in the Flood.
7. The testimony of Peter (II Peter 2:5; 3:6) is that the world was destroyed by the Flood.



7B-5 *An artist's rendering of Noah's Flood, showing the depositing of layers of organisms.*

PAHG ruh fee), or land features, with which we are familiar. Rock layers are visible where mountains have been cut away by rivers as in the Grand Canyon or by man as in building roads. According to the deluge theory of fossil formation, these rock layers were formed by Noah's Flood.

7B-6 *The erosion of the Badlands in South Dakota is presumed to have taken millions of years. However, the amount of water involved in the Flood could have formed this and similar structures quite rapidly.*



Several conclusions about fossilization can be made which support the deluge fossil formation theory and contradict the progressive fossil record that evolutionists imagine.

❑ Abundant fossilization is not taking place today. Sometime in the past, however, fossilization rates must have been vastly different to account for the fossils we find in our present world.

❑ The abundance of fossils and the arrangement of the fossils indicate a major catastrophe.

❑ Fossilization of an organism's parts must be rapid; otherwise, organisms would decompose before fossilization could take place.

❑ Most types of fossils we find today apparently required water movements for depositing them.

❑ Most of the fossils we find today apparently required water for their formation.

Some evolutionists, recognizing the problem of fossilization, suggest that there must have been a series of major catastrophes to account for the fossils we find today. These catastrophes would have to have been separated by long ages, and each one could have formed only a few layers in order for the fossils to verify evolution. The fossils themselves present problems even for *these*

7B-7 *A polystrate fossil runs through several layers of sedimentary rock. Such fossils should have decayed before they formed if the sedimentary layers represent thousands of years as evolutionists claim.*

Stress these five conclusions about fossilization.

Polystrate fossil is another term students should know for testing purposes.

This Facet should be read by the students, but it is not necessary to spend much time on it in class.

There are no terms in the Facet which are listed in the Biological Terms section at the end of the chapter. This Facet seeks to take Noah's ark and the Flood out of the context of a children's story and place it in the framework of a Biblical event with major scientific significance.

This particular box-shaped ark is favored by many scholars. The ark was going nowhere; it was merely designed to stay afloat. The pointed bow of today's ships was unnecessary.

A length of about $1\frac{1}{2}$ football fields is equal to 137 m (450 ft.), and 23 m (75 ft.) is about $\frac{1}{2}$ the width of a football field. Each deck had the floor space of about $\frac{3}{4}$ of a football field.

7B-1

FACETS OF BIOLOGY

Noah's Ark and the Animals

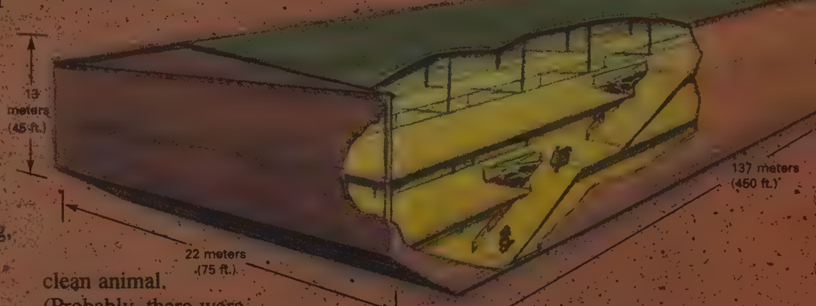
To many people the story of Noah with the animals on the ark is a delightful children's story which clearly teaches God's punishment for sin and His watch care over His children (and animals). The details and implications of the Biblical account, however, teach us even more about God and His creation.

Based on the Genesis account and a 0.46 m (18 in.) cubit, the ark was over 138 m (450 ft.) long, 23 m (75 ft.) wide, and 14 m (45 ft.) high. It contained 3 internal decks with a total deck area of over 9,500 sq. m. (101,000 sq. ft.), larger than 20 basketball courts.

The ark was probably box-shaped rather than streamlined like a modern boat. Its purpose was simply to float through a severe flood, not to travel anywhere. A completely enclosed structure strengthened by the 3 internal decks, it would have to be turned almost halfway over to capsize. Made completely of wood and covered with pitch (probably a tar-like substance), only major structural damage could have sunk it. Although Noah built a good vessel, the reason for the ark's successful passage through the Flood was that "God remembered Noah, and every living thing, and all the cattle that was with him in the ark" (Gen. 8:1).

Many people have said that the ark could never have contained all the necessary animals. Noah was told to take 7 of every kind of clean and 2 of every kind of unclean animal. (Probably, there were far more unclean than clean.) Most likely only land animals were on the ark (aquatic animals could have survived in the water). Today there are less than 17,500 species of vertebrate land animals such as mammals, birds, reptiles, and amphibians. Noah's ark, therefore, needed to carry about 35,000 vertebrate land animals.

Dimensions of the ark. Figures inside the ark are drawn to scale.



A sheep is about the average size of the animals taken on the ark. A double-decked railroad stock-car can carry 240 sheep. Only 146 stock-cars would be needed to carry 35,000 ark animals. The only major group of invertebrates to have land-dwelling members includes the insects and a few similar organisms. An additional boxcar or two could contain these. The ark had a total volume of over 530 boxcars, even though only the volume of about 150 was needed to hold its inhabitants.

Noah did not need to catch the animals. The Bible states that God brought the animals to the ark (Gen. 6:20; 7:9, 15). Some people ask if there were dinosaurs or other now-extinct organisms on the ark. The Flood theory of fossil formation assumes dinosaurs were alive in Noah's day. God possibly brought dinosaurs (perhaps young ones) to the ark. There was easily enough room for them.

It is also possible that God, knowing that the after-the-Flood world would not be suitable for large dinosaurs, did not bring them and other now-extinct animals to the ark. Some Christians object to this idea, saying that Noah was to take two "of every living thing of all flesh" (Gen. 6:19) and dinosaurs must have been included. But the next phrase of the verse states "two of every sort." It is possible that the "sort" that included dinosaurs was represented by smaller reptiles, possibly some that we are familiar with today.

Others argue that God would not completely destroy organisms He had created. However, other organisms, for which God's purpose must have been finished, have become extinct since the Flood. God could have destroyed creatures outside the ark in the Flood as easily as He could have destroyed them after the Flood.

Some people see Noah as a harried, understaffed animal keeper with only 7 helpers, running from cage to cage trying to keep things clean and the animals' food and water bowls filled in a rocking, floating zoo. Others wonder how Noah could supply meat for the carnivores without killing some of the animals on board and plants for the vegetarians without a sizable storehouse.

A possible answer is that many of the animals entered into a state of dormancy (hibernation or other quiet states) for the year on the ark. If so, this was the first hibernation that some animals needed. Possessing a canopy, the antediluvian world probably would not have had the major seasonal changes we experience today. Environmental changes are the primary reasons many animals need dormant periods.

Some people object, saying that this would require a miracle from God. But the Flood, the ark, and the animals coming to and entering the ark were all miracles. God finishes the work that He begins. It is not likely that God would have permitted His creatures to harm one another or be overly demanding on Noah and his family. (See *Biblical Kind*, Chapter 8.)

Review questions on page 184.

Finding Noah's Ark

Periodically various Biblical artifacts have supposedly been found, and Noah's ark is one such artifact. There are several remote places in the world today where Noah's ark is supposedly resting.

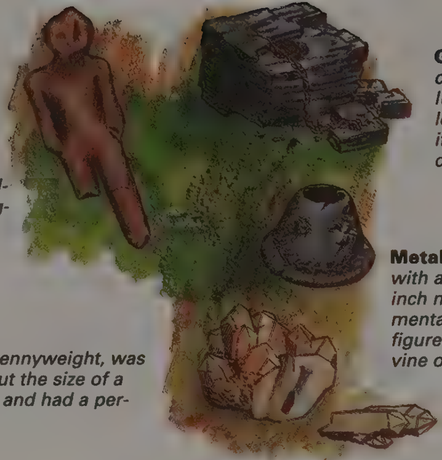
If a structure which matches Noah's ark is found, it might lend support for the inerrancy of the Bible, but it would do little to increase the faith of Bible-believing Christians. Would finding Noah's ark lead people to Christ? As Abraham told the rich man, "If they hear not Moses and the prophets, neither will they be persuaded, though one rose from the dead" (Luke 16:31).

If Noah's ark is ever found it will be the only physical Biblical artifact we have today. The Jews do not have the Ark of the Covenant, the Tabernacle, or the Temple, all very important to their obedient worship. We do not have any of the original manuscripts of the Scripture.

What would we do with a Biblical artifact if we had it? Hezekiah had to destroy the brazen serpent that Moses lifted up in the wilderness because the children of Israel started worshiping it (II Kings 18:4). Perhaps we do not have Biblical artifacts because we would reverence the objects rather than worshiping God. If Noah's ark is still in existence and is ever found it will probably be used in such a way that most Bible-believing Christians would wish it had not been found.

Roman Catholics revere Biblical artifacts, like the coin from the fish's mouth used to pay the tax, the shroud used to wrap Christ for burial (the Shroud of Turin), and the "splinter of the true cross" (of which it has been said there are enough to build Noah's ark). They believe that making pilgrimages to view these artifacts, touching them, and kissing them will result in time off one's purgatory sentence. However, none of these "holy artifacts" has historic or scientific authenticity. The locations of most specific Holy Land places revered as Biblical locations (e.g., the Garden of Gethesemane, the Garden Tomb, Calvary) are of questionable authenticity. Even the Wailing Wall may not be from Solomon's temple, as some Jews claim, but rather part of the foundation of the stables of Herod's temple.

7B-8 *Some human artifacts*



Nampa image *During a well-drilling operation, a carved human figure was discovered 300 feet below the surface.*

Gold chain *A 10-inch-long, 8-carat gold chain was found in a lump of coal. Both ends were left embedded in the coal when it broke open, revealing the chain.*

Metal jar *A jar 4 1/2 inches high with a 6 1/2-inch base and a 2 1/2-inch mouth was found in solid sedimentary stone. It bears six carved figures, flowers, and a wreath or vine of inlaid silver on a zinc alloy.*

Nail in quartz *A nail, about 6 pennyweight, was found in a quartz formation about the size of a man's fist. The nail was straight and had a perfect head.*

evolutionists. **Human artifacts** (things which man must have made such as gold chains or metal objects) or fossils such as bones and footprints have been found in low fossil layers. If the progressive catastrophes theory held by these evolutionists is correct, man must have evolved very early.

Some Christians adopt a theory similar to that of these evolutionists. Calling Noah's Flood the most recent catastrophe, they put the other catastrophes within the "gap." The human artifacts then indicate that the before-the-gap creation must have included man. Adam then is not the *first* man but merely the first man of the new (present) creation. Romans 5:12 reveals that it was in Adam's sin that death entered the world. Human artifacts from a time before Adam would contradict this Scripture. Those who believe the deluge fossil formation theory, however, explain fossilized human artifacts by saying that they are from the antediluvian civilization that God destroyed with the Flood.

Review Questions 7B-2

1. List several methods of fossilization.
2. List seven Biblically based reasons why we believe the Flood was universal.
3. Why is the deluge fossil formation theory the most scientifically acceptable theory for fossilization? Is it also a Scripturally acceptable theory?

Facet 7B-1: Noah's Ark and the Animals, pages 182-83

1. List several objections that people have to the Scriptural account of the animals' being on Noah's ark, and give answers to the objections.
2. Compare the size of Noah's ark to the size of some familiar objects.

Some students ask why the Bible does not record dates. This question cannot be completely answered. In most cases the descriptions of time ("in the third year of the reign of"; "in the year that King Uzziah died") were sufficient to place the time of the event. However, dates of the Flood and all events before it can only be surmised. God in His wisdom did not see fit to reveal this truth.

The Age of the Earth

In the 1600s, James Ussher, an Irish Anglican clergyman, tabulated the dates of various Biblical events by using the ages of people recorded in Scripture and other available historical records. His dates appear in many reference Bibles (including the *Scofield Reference Bible*). In *The Annals of the Old and New Testaments*, published in 1658, Archbishop Ussher placed creation at "the entrance of the night preceding the twenty third day of Octob. in the year of the Julian Calendar, 710" (4004 B.C.). Although most people are a bit skeptical about Ussher's exact date and

Answers–Review Questions 7B-2

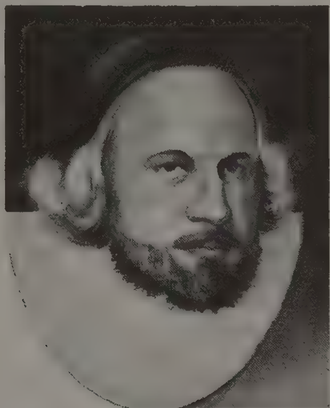
1. Preservation of parts (bones, teeth, shells, stems, seeds), preservation of carbon (coal), preservation of forms (casts or molds), preservation of tracks, petrification, and freezing
2. See box on p. 180.
3. **(1)** Sedimentation caused by the the Flood accounts for the layers of sedimentary rock which contain most of the fossils and compose most of the topography. **(2)** Abundant fossilization is not occurring today. **(3)** The abundance of fossils and their arrangements indicate a major catastrophe. **(4)** Fossilization of an organism's parts must have been rapid. **(5)** Water movement is apparently necessary to deposit most types of fossils. **(6)** Most types of fossils found today required water for formation. Yes, it is also a Scripturally acceptable theory.

Answers–Facet 7B-1

1. **(1)** "The ark was too small to hold all the animals." Based on the size description in Genesis and the number of animals believed to be on the ark, there would have been adequate room. **(2)** "The large animals, like dinosaurs and elephants, would not fit on the ark." There was no problem fitting elephants on the ark. If dinosaurs were on the ark, young ones or smaller representatives of the "kind" could have been chosen. **(3)** "Taking care of the animals for the length of time they were on the ark would have been impossible." It is possible that the animals hibernated. It is true that "God remembered" all that were in the ark (Gen. 8:1). **(4)** "Noah could not have gone out and collected all the animals needed to represent two of every kind of animal known today." Noah did not go collect the animals; God brought them.
2. Its 3 decks had about the same area as 20 basketball courts. Its volume was greater than 520 boxcars.

time of day, you can, if you use the Biblical genealogies, arrive at about the year 4000 B.C. (about 6,000 years ago) as the time of creation.

Many Bible scholars, however, agree that Ussher's dates are most likely a bit short. Several Biblical statements show that there are deliberate gaps in some of the genealogies. Compare Gen. 11:12-13 and Luke 3:35-36. These gaps permit dates of creation extending slightly in excess of 6,000 years ago.



7B-9 *Archbishop James Ussher proposed dates for creation based on Biblical events.*

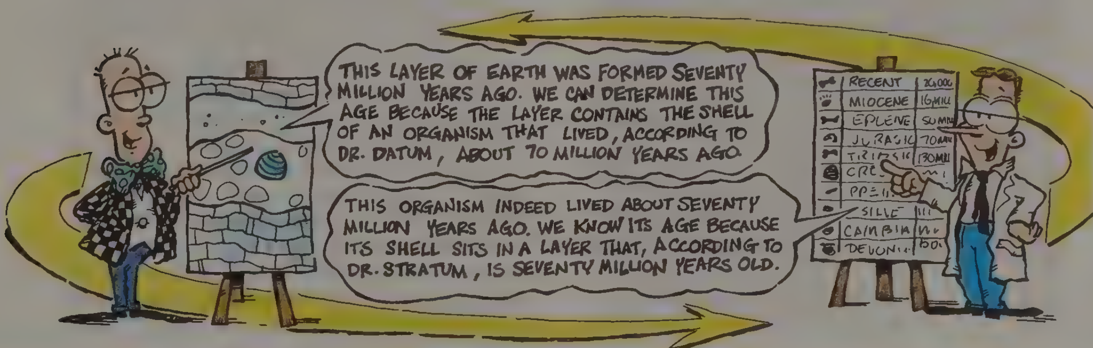
Probably more accurate, and acceptable within the Bible's framework, is that creation was between 8,000 and 10,000 years ago, although some creationists admit that it might be several thousand years older than that. This age of the earth is in keeping with various historical dates recorded by ancient peoples. One such date is given in an ancient translation of the Bible, the Septuagint, which places Noah's Flood at 3700 B.C. rather than Ussher's 2348 B.C.

Most evolutionists believe that the earth is billions of years old. The evolutionists claim that dates for the beginning of the earth could not have been recorded because man had not yet evolved. They choose to ignore the Word of God, which contradicts their theories on such matters. Evolutionists, therefore, must use other theories to support their hypotheses. These theories fall into two groups:

- *The earth must be old because biological evolution must have taken a long time.* Creationists agree that biological evolution would have required a long time *if* it had taken place. But Christians cannot accept this argument for an old earth because the Bible says God directly created living things (see John 1:3).
- *The earth must be old because of the physical evidence the earth supplies.* Such evidences fall into three basic categories: dating of fossils, dating by **topography** (the shapes and contours of the earth), and dating by decay or buildup of substances. Dates obtained from the physical earth, however, are circumstantial and often depend upon the assumption that biological evolution took place.

Dating of fossils

A person who counts the number of layers above a fossil and then attributes a certain age to each layer is assuming that fossils were formed progressively. But as we have seen, fossils are probably the record of one major catastrophe, Noah's Flood. Even if they are a record of several major



Ussher states that Adam and Eve were expelled from the Garden on the first day of the week after creation. If so, Adam must have done a lot of animal naming the day he was created. Scripture seems to indicate that Adam and Eve had walked together with God in the cool of the day before they were expelled from the Garden, because they recognized God's coming. It is conceivable that Adam and Eve lived for weeks, months, years, or even centuries in Eden. Adam's age (Gen. 5:3-5) could be counted *after* he sinned.

Visual 7B-1 can be used to teach the kinds of fossils and their formation.

An evolutionary timetable would be found on a phylogenetic tree (see p. 192). Assuming it takes *X* years to go from one organism to the next on the tree, figuring an evolutionary timetable is done by multiplying *X* times the number of steps between the index fossil and the one they want to date. If later it is discovered that it takes longer than *X* for evolution to take place, recompute. This is basically why the evolutionary dates for the age of the earth have grown.

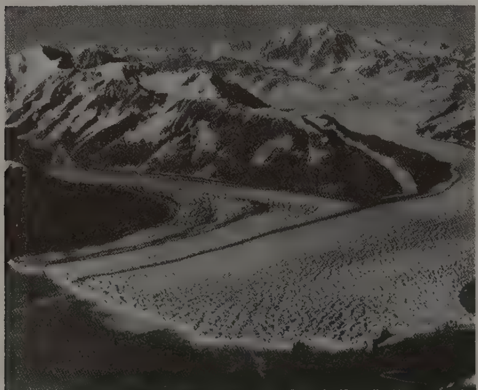
Visual 7B-2 can be used as an outline to teach the methods of dating the earth.

catastrophes, it would be difficult, if not impossible, to determine which layers belong to which catastrophe and what period of time to assign to each layer.

Evolutionists often use another method to determine the age of the fossil: they consult an evolutionary timetable of when organisms supposedly developed. When consulting such a chart, the evolutionist is assuming not only that biological evolution occurred but also that the fossil record is progressive.

Evolutionists often use *index fossils* to tell the age of other fossils in the same area. An index fossil is the remains of an organism (usually an extinct animal) which supposedly lived at only a certain time in evolutionary history. When an index fossil is found in a layer of rock, evolutionists believe they can consult evolutionary timetables and thereby accurately date that layer as well as the fossil layers above and below it.

If you analyze the above statements, you can see that dating of fossils by the fossils themselves is primarily guesswork. It often winds up with one scientist's quoting another scientist as the authority for their dates. If the other scientists have merely guessed at the date, we still have only a guess, not a scientifically determined age of a fossil. Many scientists, thus, look to other dating methods to determine the age of fossils.



7B-10 *A glacier similar to this one may have covered portions of the earth for a brief period following the Flood.*

Dating by topography

Evolutionists claim that a force of relatively recent origin pushed up on the earth's crust to form mountains. They conclude this because they have found fossils of land vertebrate animals, as well as those of fish and marine animals, at tops of many mountains. These fossils indicate that the mountains were once underwater and were formed after these organisms had evolved.

Evolutionists find it difficult to set a time for both the mountains to have been underwater and the major upheaval that formed vast mountain ranges such as the Himalayas or the Rockies. But Noah's Flood, which covered the mountains, is a sufficient explanation, not only of when the ranges formed but also of what forces formed them. The Flood theory of fossil formation can easily account for fossils on the tops of mountains.

Evolutionists use ice ages–major periods of **glaciation** (GLAY she AY shun)–to explain many of the earth's present features. They say that vast expanses of ice covered entire continents for thousands of years. As the North American ice sheet moved back and forth, it flattened the midwest regions of Canada and the United States, hollowed out the Great Lakes, and deposited larger rocks in the middle of flat prairies.

Setting dates for the ice ages is a major problem. Some Christians attempt to place them in the gap of the gap theory. If they occurred in the gap, though, physical evidence of them would have been destroyed in the deluge, and we would not know that major glaciation periods even existed.

The ice ages as described by most evolutionists probably never happened. Some of the supposed topographic effects of glaciation could easily have been the result of water movements during the Flood. A very brief period of glaciation in certain areas of the world may have taken place immediately after the Flood. Without the protective canopy, the adjusting earth may have had a period of glaciation before it reached the relative stability of today's climate and seasons. This ice which formed after the Flood may have contained some Flood-destroyed organisms, thereby accounting for some of the frozen organisms found in areas of the world today.

Answers–Review Questions 7B-3

1. He based this date on the ages of people and other events recorded in Scripture and other available historical sources.
2. Evolutionists base their estimation of the earth's age on evolutionary theories. The earth must be old because biological evolution requires a great amount of time; physical evidence from dating methods (which they calculate according to their theories) indicates great age.
3. Dates for fossils are sometimes obtained by counting layers above the fossils and assigning ages to the layers.

7B-11 *Scientists once believed that stalactites and stalagmites like the ones on the left took many millions of years to form. Under the Lincoln Memorial these stalactites and stalagmites formed in fewer than 50 years.*

Cave formation and the forming of stalactites* (stuh LAK TITES) and stalagmites (stuh LAG MITES) in caves, according to many evolutionists, take hundreds of thousands of years. The receding water of the deluge, however, could have caused rapid cave formation. Stalactites and stalagmites can form quickly under the proper conditions. These conditions probably existed immediately after the Flood, as the caves were forming.

Some scientists also believe that many other features of the surface of the earth took millions of years to form. Evolutionists often use rocks (like limestone), deposits of underground salt, and major evidences of erosion (like the Grand Canyon) to date the earth as very old. Because large quantities of similar structures are not being formed in the world today (if they are being formed at all), evolutionists require the old dates to account for these features. But these and many similar geologic phenomena are more easily and more scientifically explained by a major water catastrophe. Most Bible believers claim that that catastrophe was Noah's Flood.

stalactites: (Gk. STALAKTOS, dripping)

Since the Lincoln Memorial in Washington, D.C., was completed in 1922, stalactites and stalagmites several feet long have formed in the space between its limestone floor and its foundation.

Review Questions 7B-3

1. On what did Ussher base his 4004 B.C. date of creation?
2. On what do evolutionists base their 4.5 billion-year-old earth theory?
3. Describe how scientists use fossils to date fossils and tell why this is an unacceptable method of determining the age of a fossil.
4. What are some of the topographic features which evolutionists attribute to glaciation? How do most Bible-believing Christians account for these features?
5. What topographic features do evolutionists often use to arrive at old dates for the earth?

Dating by decay or buildup

If a person examined the stump of a candle, measured it carefully, and then made the statement that the candle had burned 2 hr. 28 min., you could ask him how he knows. He might say that in the environment in which he found the stump, an 8 in. candle of the same diameter as the first candle would have had to burn 2 hr. 28 min. to reach the final size of the first candle.

All his statements may be accurate and even testable. The several assumptions he is making, however, make his statement pure guesswork, rather than science. He is *assuming* that the candle started at 8 in. long, was the same diameter all the way up, and burned only in the environment in which he found the stump. One or all of these assumptions may not be true. An error in any of them could affect the accuracy of the estimation, perhaps by as much as several hours.

The same principle applies to using the decay or buildup of substances to determine the age of the earth: underlying these methods are many speculative assumptions. Using these methods one can obtain "proof" that the earth was formed billions of years ago, several thousand years ago, yesterday, or even *not yet*. Obviously, dates which say the earth has not yet been formed are wrong, but which of the others should one accept?

Individuals generally accept the dates closest to their personal beliefs. Evolutionists are biased for the old dates and therefore often cite them as accurate. They either ignore the more recent dates or consider them wrong since such dates do not fit into *their* evolutionary timetable.

Several days before coming to this topic, plant a pea seed in a pot and put it in a dark, warm area, such as a closet. Place the pot in front of the students. Ask them how long ago the seed was planted. When they say they don't know, offer information. Pea seeds germinate within 3 to 4 days under ideal conditions. Under ideal conditions a pea seedling grows $\frac{1}{4}$ inch per day for the first 2 days, $\frac{1}{8}$ inch per day for the next 10 days, followed by $\frac{1}{4}$ inch per day until it starts blooming. All of this is hypothetical. Ask again when the pea seed was planted. After some measurements they will come up with an answer. It will be incorrect because the pea was brought up under unfavorable conditions–lack of light. Could data be obtained for this condition? *(Yes.)* Do other factors affect rate of growth? *(Yes, such conditions as temperature and availability of water can affect rate of growth.)* Could data about these be obtained? *(Yes.)*

Show the students the closet where the pea was raised. Tell them the temperature in the closet and the amount of water put into the soil. Can they now tell when the seed was planted? Could it have been planted and not watered for several days? Is the closet at a constant temperature? There is no way to accurately say when the seed was planted except by observation of the seed's being planted.

It is possible to draw parallels between this illustration and scientific dating by decay or buildup.

Dates are obtained by looking at evolutionary timetables based on length of time assumed necessary for evolution of the organism. Index fossils, fossils with an assumed date, are often used to justify or establish dates of other fossils. All of these dates are based on assumptions which are unacceptable because they lack scientific observation and have no Biblical basis.

4. Some are the flattened midwest regions of Canada and the United States, the Great Lakes, and large rock deposits in the middle of flat prairies. Most Bible-believing Christians account for these features as results of the Flood. A short period of glaciation may have occurred immediately after the Flood.
5. Mountains with sea-animal fossils near the top, supposed effects of glaciation that they assume took a long time, cave formation, major erosion (the Grand Canyon), and some mineral deposits like salt and limestone

It is not crucial that students memorize the facts given in this box regarding young-earth dating methods, since such facts will be easily forgotten. It is crucial that students realize that there are methods of dating the earth which do suggest a young earth and are as scientific (if not more so in some cases) as those which suggest an old earth. Consider spending 5-10 minutes on this chart in class.

Dating Methods That Suggest Relatively Recent Dates for the Age of the Earth

Volcanism Most evolutionists believe that there must have been more abundant volcanic activity in times past. If the current rate of lava production of today's approximately 450 active volcanoes were constant for 4 1/2 billion years, the amount of lava produced would be equivalent to the size of the earth. If at current volcanic activity the earth could not be that old, it certainly could not be that old if volcanic activity had ever been greater.

Water formation Water is being formed (either by volcanic activity or other means) and added to the earth at the rate of about 1 cubic mile per year. If the earth were billions of years old, far too much water would have been produced for there to be any dry land.

Meteoric dust Today about 14 million tons of dust from outer space fall to the earth each year. Estimates indicate that in about 4 billion yr. enough meteoric dust would have fallen to cover the face of the earth a depth of 54 ft. to 100 mi. This dust has characteristic chemicals in it (nickel, cobalt, and other heavy metals) which are relatively rare in the earth's crust. We do not find this amount of meteoric dust (or even the evidence of the proper chemicals) in adequate near-the-surface sources. Even if swept into the ocean by wind and erosion, these chemicals should show buildups somewhere on the ocean floor. Such abundance of these chemicals, however, is not found even there.

Soil formation Evolutionists have stated that soil takes thousands or even millions of years to form. In several areas of the world, however, actual measurements have accounted for several inches of soil being formed in less that 100 yr. This rate of formation indicates that the earth is young.

Human population statistics Considering plagues, wars, famines, and other problems affecting population, 8 people at the time of Noah's Flood would have multiplied to almost 4 billion people today. This figure is about correct. Evolutionists, claiming that man evolved a million years ago, have problems explaining why, using the same mathematical calculations, there are not an astronomical number ($10^{27,000}$) of people on the earth.

Decay of the earth's magnetic field The earth's magnetic field is decaying at a certain rate (based on measurements for the past 100 yr.). At the present rate of decay, if the earth's magnetic field is figured backwards, about 7,000 yr. ago the earth's magnetic field would have been 32 times stronger than it is now, which is the highest limit of possibility. Ten thousand years ago the earth would have been as magnetic as a magnetic star, which is improbable.

Scarcity of helium Many radioactive decay processes form helium. If radioactive decay processes had been going on for billions of years, large quantities of helium should be found in the earth's atmosphere. Helium, however, is relatively rare. Its quantity accounts for an earth with radioactive decay at present rates for only several thousand years.

Apparent age is sometimes represented by the question: "Did Adam have a navel?" The navel is the remains of the point of attachment to the womb. Adam did not come from a womb. Did God create Adam as if he had an apparent birth from the womb, or was he without a navel? Whether or not Adam had a navel is immaterial. He must have had apparent age, however, to be able to take care of himself.

Creation with apparent age

People often fail to consider that the earth must have been created with **apparent age.** Adam was not an infant on the seventh day of creation. Even though he was just a day old, he had the body of at least a young adult who was able to care for himself. The same was true of the animals. The Garden of Eden had fruit-bearing plants, not just seeds and seedlings.

The earth itself must also have had some apparent age. Although streams, soil, and many other features of the earth take time to form, we find them described as being in God's newly formed creation. If a person had measured the soil depth in Eden the day after creation week and had calculated the age of the garden based on the length of time required for soil production, he undoubtedly would have come up with an age for Eden considerably older than it actually was.

This creation with apparent age throws off some of the buildup and decay clocks that evolutionists use to date the earth. Scientists who measure how rapidly certain chemicals are building up in an ocean, and then compute backwards to a point where none of these chemicals were yet in the ocean, obtain an apparent age but not an actual age, since the newly formed seas already had an amount of these chemicals dissolved in

them. If a scientist knew exactly how much of certain chemicals was actually in the sea at creation and knew all the factors (including the Flood) that could affect the further buildup of these chemicals, he could more accurately determine the age of the earth. But this information is not available.

Dates for the age of the earth that are based upon chemicals found in seawater range from just over one hundred years to well over a billion years, depending upon which chemical is measured. It is interesting to note, however, that virtually all the chemicals in the ocean give dates for under a billion years, considerably less than most evolutionists would like.

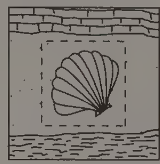
Most processes of decay or buildup produce relatively young dates for the earth. Moreover, those in this category that can be considered more reliable (those with fewer variables) appear to give younger dates than most others.

Radiometric dating methods

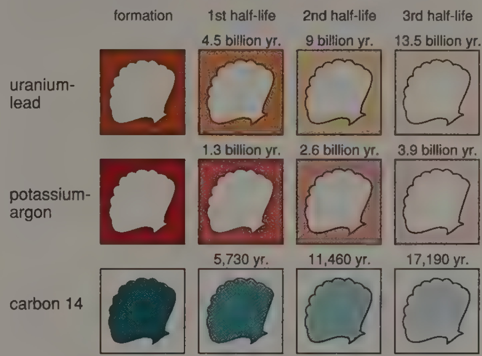
Although highly favored by evolutists because they often give very old dates, radiometric* (RAY dee oh MET rik) dating methods are losing scientific credibility because of faulty assumptions and measurement problems. A **radiometric dating method** measures the decay of a radioactive substance into a nonradioactive substance. Probably the best-known of the radiometric dating methods is the *uranium-lead method.*

Uranium, a radioactive element, decays over a period of time into 15 different subproducts before finally becoming one of the several forms of lead. An atom of uranium-238 (an isotope of uranium with 238 elementary particles in the nucleus) decays to an atom of lead-206 and 8 helium atoms. One gram of pure uranium-238 would take approximately 4.5 billion yr. to become 0.5 g of uranium-238 and the appropriate amounts of lead-206 and helium. In another 4.5 billion yr. it would form 0.25 g of uranium-238, and so on. Uranium-238, therefore, has a **half-life** of 4.5 billion yr. That is, one-half of the existing amount disintegrates in that amount of time.

Other isotopes of uranium have different half-lives and become other isotopes of lead. Most of the other radiometric dating methods (potassium-argon, rubidium-strontium, and others) are quite similar. At present there is some question regarding the accuracy of past measurements of the half-lives of many substances.



7B-12 *Scientists attempt to date fossils, using radiometric dating methods. This presumes a known starting amount of the radioactive substance in the specimen as well as many other untestable "facts."*



A scientist can measure (with a degree of accuracy) the amount of uranium and the amount of lead in a rock sample. If, however, the scientist then makes a statement regarding the age of that rock based on the ratio of lead to uranium in it, he is assuming several things:

- The rock when it was formed contained all uranium and no lead.
- The rate of decay has been constant throughout all the time since the rock was formed.
- None of the uranium, subproducts, or lead escaped from the rock since it was formed.

In essence, the scientist is assuming the same things as the person who guessed how long the candle had burned. Good evidence indicates, however, that these assumptions are not valid.

Variables in the radiometric dating methods

To assume that there is no lead in newly formed rock is a fallacy. The radiometric dating of rock from recent (less than 200 yr. ago) volcanic activity often yields dates in the millions or billions

radiometric radio- (to emit beams) + -metric (measure)

Do not overemphasize radiometric dating methods. It is not essential that students memorize the half-life of uranium and the end products of the decay of uranium-238. Students should see enough of the method to realize the extensive possibilities for mistake and error. Having the class compose a list of problems with radiometric dating methods could be beneficial.

This box contains supplemental material which should be studied by most students. Omit this box if time is limited. This box presents the problems of carbon-14 dating.

The term **radiocarbon dating method** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Ask the students to come up with a list of problems with the radiocarbon dating method. Compiling the list in class would be profitable.

Visual 7B-3 can be used to teach about the radiocarbon cycle.

This round-robin approach to authenticity is all too prevalent not only in evolutionary logic but also in Christian logic. Continually quoting people to give authority to something is really of little value when the Bible is silent on the topic.

The Radiocarbon Dating Method

The **radiocarbon dating method** *or carbon-14 dating method* can be used to date substances that were once alive. Most of the carbon on the earth and in the atmosphere is the nonradioactive isotope carbon-12. In the atmosphere about 6 mi. up, carbon-14 is formed by cosmic radiation bombarding nitrogen. As soon as carbon-14 is formed, it begins to degenerate into nitrogen. The half-life of carbon-14 is *about* 5,730 yr. (Figures vary as much as 200 yr.)

Carbon-14 in the atmosphere combines with oxygen, forms carbon dioxide, and spreads throughout the air. Only a small amount of atmospheric carbon dioxide is made of carbon-14. Carbon dioxide (both of carbon-12 and -14) enters the photosynthetic process of plants and in time is passed to all other living things.

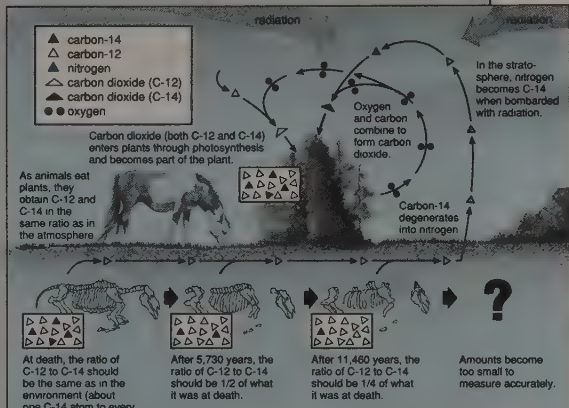
When an organism dies, it stops taking in carbon-14. Scientists can measure the carbon-14 and carbon-12 in a specimen and obtain a ratio. By comparing this ratio to the ratio of carbon-14 and carbon-12 in currently living things, scientists date the specimen, finding the time that its organic elements were last in a living thing.

The radiocarbon dating method can give reliable dates within the framework of several thousand years. Since the ratio of carbon-14 to carbon-12 on the earth is very small, the tiny ratios obtained when measuring the carbon-14 of a supposedly very old organic substance are doubtful.

Scientists realize that if the amount of radiation coming to the earth from outer space was at any time significantly different from the present amount, the dates obtained by radiocarbon dating would be unreliable. Evidence shows that the rate of radiation from the heavens has not always been the same. One can only guess what effects these different rates and the antediluvian canopy which would have filtered out various types of radiation would have.

Before accepting carbon-14 dating, a person must consider its several assumptions:

- ❑ The method assumes that the amount of carbon-14 forming in the atmosphere is now, and always has been, constant. We know by measurements that the carbon-14 to carbon-12 ratio is increasing. More is being formed than is degenerating. Differences in cosmic radiation (of which there is evidence) could be the reason.
- ❑ The method assumes that there is an equilibrium of carbon-14: the amount of carbon-14 forming equals the amount decomposing into nitrogen. Assuming present conditions, this equilibrium would take about 30,000 yr. to reach. Present data shows that the carbon-14 ratio is increasing, indicating that the ratio has not yet reached an equilibrium (as those who believe in a young earth are not surprised to learn).
- ❑ The method assumes that the carbon-14 decay rate is constant. It can be demonstrated that the decay rate is not constant.



Radiocarbon Cycle

- ❑ The method assumes that the amount of carbon-12 available to the organisms is constant. The abundance of carbon fossils (coal, oil) indicates that the amount of carbon-12 available has probably not always been the same.

The radiocarbon dating method is probably the most reliable method of dating organic materials of unknown age. But it obtains reliable dates only within certain limits. For relatively short periods of time (up to a few thousand years) the method can accurately tell the age of some specimens. Dates which are very old or are based on specimens which may have been kept in unusual conditions should be "taken with a grain of salt." Radiocarbon dating is not infallible. There are a number of specimens for which the method has given wrong dates. Shells taken from living clams have been dated thousands of years old.

Answers–Review Questions 7B-4

1. Many speculations and assumptions underlie these methods; people often fail to consider that the earth was created with apparent age and that the deluge radically affected topography.
2. A radiometric dating method measures the decay of a radioactive substance into a nonradioactive substance (e.g., uranium-lead method). By determining the ratios of these substances in a sample, a guess at the age can then be made.
3. (1) In the uranium-lead method, the sample containing uranium and lead in-

of years old. These old dates occur primarily because of the lead (or other decay products) in the rocks. It is also interesting that, because of the decay products, lava from a single eruption yields many vastly different dates.

Because many of the products and subproducts of radioactive decay easily escape from rocks by exposure to water or even air, the accuracy of dates obtained is even more questionable. Furthermore, when measuring these substances, scientists are measuring minute amounts: the slightest error could change a date by hundreds of thousands or millions of years. For potassium-argon, one of the more popular radiometric dating substances, scientists have demonstrated that its half-life can be altered even by pressure and heat. In order to use this method, one must know all the conditions at which the substance has been kept since it was formed.

In order to account for these variables, scientists try to set the radiometric clock by dates from other sources. For example, when they test a rock found near an *index fossil* (a fossil which has been assigned a date by some other dating method) and the rock yields a certain ratio of the radioactive element to its end product, they often assign the date of the index fossil to that ratio.

Since other rocks in the area have been exposed to similar conditions, they assume that they can date the other rocks by obtaining their ratios and then comparing them to the ratio of the rocks near the index fossil. In other words, they are setting the radiometric clock by the assumed date of the index fossil. The date of the index fossil, as we discussed earlier, is merely an evolutionary guess and contradicts scientific knowledge and the Bible. Setting the radiometric clock by index fossils therefore yields erroneous dates.

Biblical creationism is accepted by faith. A creationist, however, should not feel that science contradicts his faith in God's Word. Rather than being disproved by science, the Scriptural concept of a young earth is actually verified by science.

Biological Terms

long-day theory (day-age theory)
short-day theory
gap theory
antediluvian
canopy theory

Fossils and Noah's Flood
fossil
fossilization
deluge
deluge fossil formation theory
sedimentation
sedimentary rock
human artifact

The Age of the Earth
topography
glaciation
apparent age
radiometric dating method
half-life
radiocarbon dating method (carbon-14 dating method)

Review Questions 7B-4

1. List reasons why dating the earth by decay or buildup methods can be unreliable.
2. Describe the radiometric dating methods.
3. What assumptions must one make when using radiometric dating methods?
4. What technique is used to compensate for variables in the radiometric dating methods?
5. List several methods of dating the earth that indicate that the earth is young (around 10,000 yr. old).
6. What assumptions must one make when using the radio-carbon dating method?
7. List several problems that the radiocarbon dating method has which prevent it from obtaining reliable dates.

Thought Questions

1. Discuss why Ussher's date for creation is too short and why dates far more than 10,000 yr. ago are too long.
2. Check five Bible commentaries regarding the gap theory. List which ones agree and which ones disagree with the gap theory. Note carefully the reasons they give. See if you can find flaws in some of the logic used either to support or to discredit the gap theory.

itially contained no lead. (2) The rate of decay has been constant. (3) None of the subproducts or lead escaped the rock since its formation.

4. They establish dates by assigning ages based on index fossils found near the samples being dated.

*5. See box on p. 188.

*6. (1) The amount of carbon-14 has always been constant. (2) The amount of carbon-14 forming is equal to the amount decomposing. (3) The carbon-14 decay rate is constant. (4) The amount of carbon-12 available for organisms is constant.

*7. (1) The rate at which carbon-14 is forming must remain constant for the method to work. There is evidence that the rate is not constant. (2) The method assumes there is an equilibrium between carbon-14 being formed and destroyed. There is evidence that there is not yet an equilibrium. (3) The method assumes carbon-14 decays at a constant rate. Carbon-14 does not always decay at a constant rate. (4) The method assumes that the supply of carbon-12 to organisms is constant. There is evidence that the supply is not constant.

*From a box.

Answers–Thought Questions

1. Some Christians believe that Ussher's date for creation does not include all genealogies given in Scripture. The apparent gaps in the genealogies may extend the date of creation to about 8,000 to 10,000 years ago. Other periods of time (like the length of time spent in the Garden of Eden) are not accounted for by Ussher. Any extension beyond about 10,000 years would not be justifiable according to Scripture.
2. Answers will vary.

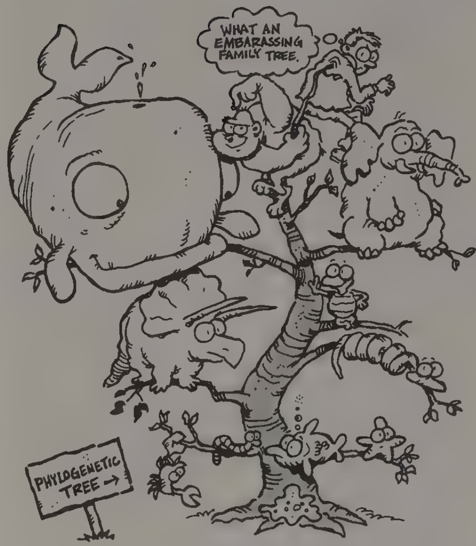
7C-Theories of Biological Evolution

phylogenetic: phylo- (Gk. PHULON, race or class) + -genetic (beginning)

Although filled with cartoon characters, this phylogenetic tree is similar to those proposed by evolutionists. Looking it over carefully will reveal significant problems.

Emphasize that missing links and common ancestors are, in most cases, the same. These missing links (not one, but billions) give evolutionists many problems.

Collect pictures of all the individuals of several families that are not known to the students. Give the pictures to the students and tell them to arrange them into families. The results can be amusing and can be used to stress the problems of trying to establish relationships based on appearances. Which appearances (e.g., hair color, nose shape) does one use? Students will often line up the photographs based on the camera view and quality of photo rather than the subject of the photo. This speaks of bias in one's judgments even when he is not aware of it.

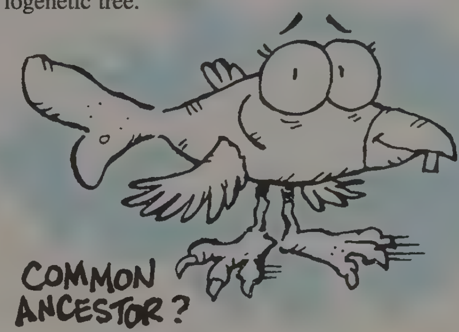


The previous section discussed the fact that there is no history of evolution recorded either by man or by fossils. This lack of evolutionary records does not disturb most evolutionists because they believe they have a model of *how* evolution took place. This model is often illustrated by a **phylogenetic*** (FYE loh juh NET ik) **tree**–a line-up of organisms based on how they are supposedly related in an attempt to show the path that evolution has taken.

It is quite natural to notice similar facial features in different members of one family. But people who look very much alike may be entirely unrelated. One organism may have characteristics similar to another organism's but not be related to it at all.

Evolutionists claim that organisms which are alike in some ways must have had a **common ancestor.** When a limb of a phylogenetic tree branches, a common ancestor is implied. A phylogenetic tree that contains many organisms and is relatively detailed usually has the known organisms (those alive today and those extinct organisms that left fossils) on the ends of the branches. The common ancestors at the forks of the branches are usually *guesses*. Many phylogenetic trees, for example, assume that the birds and the mammals both came from a common reptilelike ancestor. In one line of development, the scales became feathers and the animals became birds. The mammal-bird ancestor may be imaginatively drawn and described, but examples of this common ancestor do not exist among animals alive today or in the fossil record.

The more organisms that are included, the greater will be the difference between the phylogenetic trees proposed by different evolutionists. In other words, there is little agreement among evolutionists about which organisms are the ancestors. Although putting pictures in sequence is easy, when considering the thousands of characteristics of different organisms, it is not always easy to create a logical sequence for them. What characteristic should be used to arrange the organisms? The use of eye development will give one phylogenetic tree, and the use of leg form or another characteristic will give a different phylogenetic tree.



Creationists have no difficulty with similarities and differences between organisms. God designed each organism for a particular purpose. If four long legs are the right design for movement in one animal, it is likely that four long legs will be the best design for a similar movement in a similar animal. Similarities and differences come from God's design, not from a common ancestor.

7C–Theories of Biological Evolution

Notes–Chapter 7C

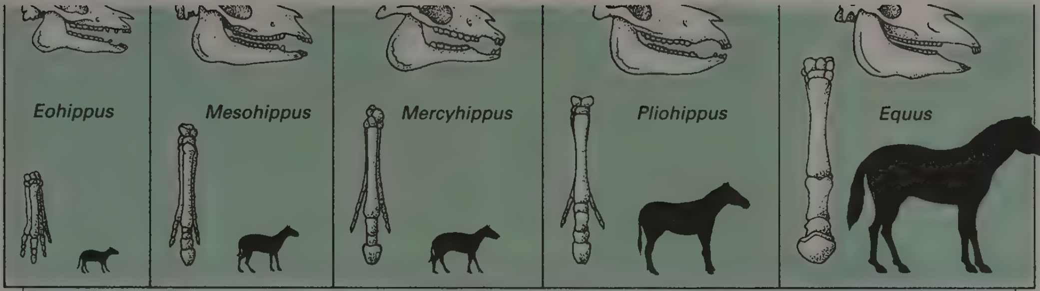
Knowing what one believes is not enough. One must also understand what others believe. If not, he will either be led astray or be unable to lead others to his position. Thus Christian students need to study evolution.

This chapter is a relatively complete description of evolutionary theory. It is far more complete than that found in most secular texts, because evolutionary theory is accepted as fact and merely woven into other topics. In addition to the beliefs, however, careful analysis of the reasons and presentation of the arguments against the theory are presented.

If one believes the Bible is the infallible, inerrant Word of God, he can easily say that an evolutionary position is not correct because "it contradicts the Bible." But a person who does not accept the Bible will not automatically take that position. Can anything be done to show an evolutionist the error of his ways?

The only thing that can be done is to show the weakness of the evolutionist's argument–and there are weaknesses–or to present scientific evidences contrary to those he uses. In general terms, this chapter provides evidence and arguments to refute the evolutionary theory. There are many books and booklets on the market which give more complete arguments and detailed explanations than is possible in a high school text book. Several of these are available from Bob Jones University Press; if interested, request a catalog.

A teacher must be careful, however, not to dwell on this material. Five years from now, few students will be able to recall the details, and they should not be taught as though expected to do so. The goal is clear exposure to these arguments so that students know they exist and know how to obtain information about them. Then they



This box contains supplemental material which illustrates the difficulties of lining up a phylogenetic relationship between extinct and living organisms. Much research regarding these (and other horse "ancestors") can easily be done by students and can be a profitable activity for advanced students.

Stress that even when fossil remains can be lined up to show a supposed evolutionary relationship, there are so many problems that evolution cannot be accepted as fact or even as acceptable theory.

The Evolution of the Horse

In order to see some of the problems involved in lining up animals for a phylogenetic tree, let us look at a well-known example often used by evolutionists, the evolution of the horse. The *Eohippus* was an organism about the size of a terrier dog, with four toes on each front foot and three toes on each hind foot. Other extinct animals have been lined up with progressively larger bodies and with foot structures more like that of the horse to form an evolutionary "path."

The evolution seems plausible until one realizes that much of the progression is art work, and much information has been omitted. The fossils of these organisms are not found in sequence in the fossil record. In fact, the fossil record gives evidence that these organisms were alive at the same time. Having the horse and the *Eohippus* alive together at an early date defeats the evolutionary purpose of the *Eohippus*, though, so that evidence has been ignored.

The supposed evolution of the horse is like a series of piers with the connecting bridges missing. In other words, this line-up of organisms, as with all such line-ups, is without in-between organisms, the **missing links** (common ancestors). According to evolutionary theory, these missing organisms *must* have existed. Research in the fossil record has not revealed any of the missing links in horse evolution. Nor does the fossil record show a clear progression between *any* two different kinds of organisms.

A creationist looking at the fossils of the *Eohippus* or the *Mesohippus* or any others in an evolutionary line-up simply observes that they are interesting animals that must have become extinct during the Flood or shortly thereafter.

The Evolution of Evolutionary Theory

Using the fossil record and phylogenetic trees has not given adequate support to evolutionary beliefs. Evolutionists have thus resorted to trying to figure out how it *could have happened,* rather than showing how it *did happen*. This tactic takes evolution out of the realm of science and puts it into the realm of guesswork.

Lamarck's theory of evolution

In 1801 Jean Baptiste Lamarck, a French biologist, was one of the first to propose a method of biological evolution based on three concepts:

- *The theory of need* In order for an organism to evolve a structure, it must need the structure.
- *The theory of use and disuse* If an organ is used by an organism, the organ will continue to evolve. If an organism stops using an organ, the organ will degenerate and disappear.
- *The theory of inheritance of acquired characteristics* If an organism acquires a characteristic, it can pass this characteristic on to its offspring.

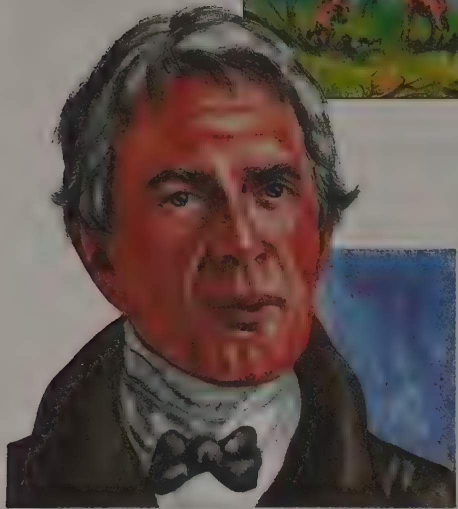
The most common example of Lamarck's theory is the proposed evolution of the giraffe. Supposedly, the giraffe's ancestors were deerlike animals on the African plain. A long drought forced these early giraffes to stretch their necks to reach higher tree leaves (theory of need). Their necks became longer with streching (theory of use). Adults with slightly longer necks produced offspring with slightly longer necks (theory of inheritance of acquired characteristics). After many generations, the giraffe's long neck developed.

Objectives–Chapter 7C

- List the three theories Lamarck used to support evolution and present evidence against each.
- List the two main parts of Darwin's theory of evolution and present evidence against each.
- Explain the difference between Darwinism and Neo-Darwinism (mutation-selection theory).
- Present arguments against mutation as the means of supplying variations needed for evolution.
- *List several so-called "fossil men" and recognize their proper places in the classification system, according to the evidence of their existence.
- *List several arguments that evolutionists use to support their theory. Present the creationist position in relation to each.
- Define, explain, and give examples of each of the following: *common ancestor, missing links, homologous structures, punctuated equilibrium, survival of the fittest, vestigial organ,* and *the theory of recapitulation.*
- Describe punctuated equilibrium and explain why some evolutionists have eagerly adopted this theory. Describe the creationist's position in relation to punctuated equilibrium.

*From a Facet.

7C-1 *Jean Baptiste Lamarck and his theory of evolution, illustrated by the giraffe*



In accord with Lamarck's assumptions, however, the story should not have stopped. Most giraffes do not need to stretch their necks for food anymore. In fact, their long necks are actually an obstacle for drinking. If anything, giraffes' necks should now be getting shorter.

Analysis of Lamarck's theory

Most evolutionists today agree that the theory of need is not an actual factor in the evolutionary process. All organisms need structures (most humans could use radar, better hearing, third hands, or eyes in the back of their heads), but the DNA which determines what structures an organism has is not affected by need.

Modern scientists have also disproved the inheritance of acquired characteristics. You inherited genes from your parents, who inherited their genes from their parents, and so on. Although a parent may have developed a certain characteristic in himself, his child will not inherit it. If your father had his arm amputated before you were

Despite the illogicality of Lamarck's theories, occasionally they are cited in popular literature as "reasons" for evolution or explanations of "how" something evolved. Look for citations and bring them into class as examples.

Visual 7C-1 can be used as an outline for discussing the development and definitions of evolutionary theory. When discussing the points, consider presenting what the author of the idea meant, what evolutionists of today think about the idea as originally stated, and what they now mean by the idea. Then present a creationist's arguments against the idea.

Lamarck's Theory and Blind Cave Fish

Evolutionists often explain the blind cave fish, found throughout the world, by the theory of use and disuse. Supposedly some fish were trapped in a cave. After many generations of total darkness, their eyes degenerated.

Scientific evidence indicates that breeding fish in darkness, even for many generations, does not affect their genes. An individual fish may become blind from not using its eyes, just as a person who lies in bed for months may be temporarily or permanently unable to walk. But the children of such a person inherit genes to permit walking. The same is true of a fish that loses its vision: its offspring are unaffected.

How do Christians account for these fish with sightless eyes? Some say the blind cave fish was created that way. Would God create a useless eye? He may have. It is more logical, however, to say that the blind cave fish are merely a pure (homozygous) strain of blind fish.

Blind organisms are known to be hatched or born. Normally these organisms do not survive. Blind fish entering a cave, however, would find themselves in an environment without competition and could survive to set up a breeding population of blind fish. This model for the beginning of blind cave fish is more scientifically acceptable then an explanation based on Lamarck's theories. Because it does not support evolution, evolutionists often overlook this simpler model.

will not be led astray and will realize that somewhere someone can give an answer. That is often all that is necessary to keep from falling prey to the enemy.

Facets–Chapter 7C

The anthropology Facet is significant for its major premise: fossils represent either humans or animals, not missing links. This Facet could be covered in as little as 5 minutes or in as much as half a class period.

The Facet dealing with evolutionary arguments is significant and should be covered by all students. It should take about half a class period.

Answers–Review Questions 7C-1

1. That organisms with similar appearances are assumed to have a common ancestor is used to justify phylogenetic trees. Objections to phylogenetic trees include the following: there is disagreement about common ancestors; these organisms do not exist now and have not been found in fossil form; there are many missing links; many of the organisms in an evolutionary sequence are only an artist's creation; evidence seems to disprove some of the sequences of a phylogenetic tree. (E.g., *Eohippus* and the horse existed at the same time.)

born would you then be born without an arm? No, your father's genetic information is for two arms.

You may inherit the genetic potential to develop a characteristic that your parents developed, but you do not inherit the actual characteristic. For example, even if a boy's father had lifted weights for years and developed a strong, muscular body, the boy does not inherit his father's build. The son may have inherited the genes to *permit* him to develop such muscles, but he will have to exercise to build his body. The same is true of musical and artistic abilities and similar characteristics.

Some people believe, however, that since God removed a rib from Adam to form Eve, all men now have one less rib than women. This belief accords with Lamarck's theory of inheritance of acquired characteristics. God's forming of woman left Adam with one less rib; however, as far as we can tell, it did not affect his genetic makeup and therefore did not affect the rib count of Adam and Eve's children. Today all normal men and women have 24 ribs.

The theory of use and disuse is unacceptable based on modern genetics. Genes can be turned off and on, but under normal circumstances use or disuse does not alter or destroy them for the next generation. Occasionally, however, an evolutionist will cite this theory to explain some characteristic in an organism.

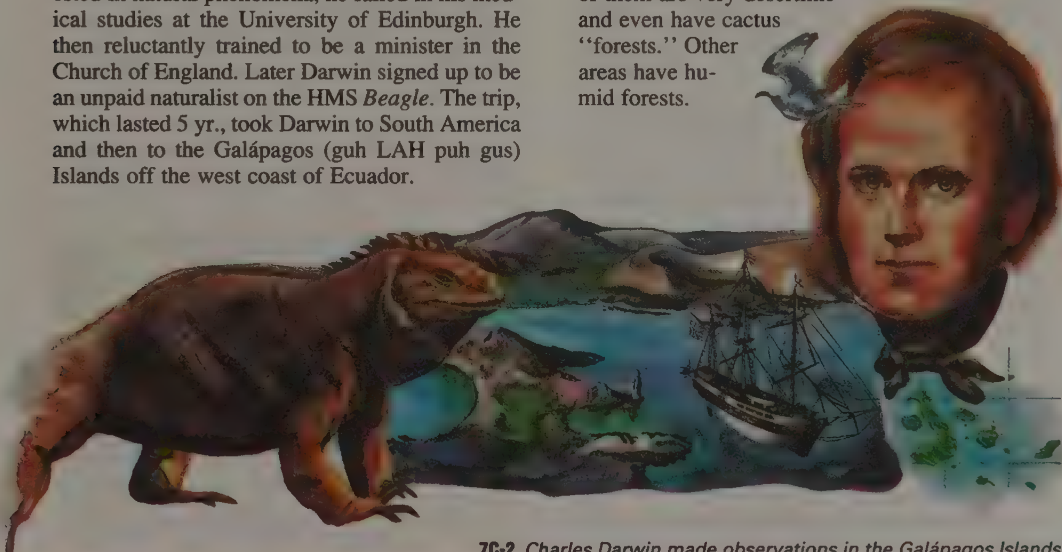
Review Questions 7C-1

1. What is the basic concept used to justify the building of phylogenetic trees? What are some objections to the building of phylogenetic trees?
2. What are some objections to the evolution of the horse proposed by evolutionists?
3. List the three basic tenets of Lamarck's theory of evolution and describe each.
4. List several objections to Lamarck's theory of evolution.

Darwin's theory of evolution

Although Charles Darwin had always been interested in natural phenomena, he failed in his medical studies at the University of Edinburgh. He then reluctantly trained to be a minister in the Church of England. Later Darwin signed up to be an unpaid naturalist on the HMS *Beagle*. The trip, which lasted 5 yr., took Darwin to South America and then to the Galápagos (guh LAH puh gus) Islands off the west coast of Ecuador.

The Galápagos Islands are the result of volcanic activity and have a varied set of habitats. Some of them are very desertlike and even have cactus "forests." Other areas have humid forests.



7C-2 *Charles Darwin made observations in the Galápagos Islands*

Although most evolutionists will point back to Darwin, if his observations and theories are carefully analyzed, they do not stand up as a method of biological evolution. It is true that there are considerable variations possible within a group of organisms (see gene pool discussion, pp. 157-58 and *The Species and the Kind,* pp. 220-23). To evolve biologically requires a great deal more than variation.

Suggested teaching outline:
Darwin's Theories
1. Survival of the Fittest
   a. Overpopulation
   b. Best overall organisms to survive to pass on characteristics
2. Pangenes
   a. Variation made by use
   b. Acquired characteristics passed on to offspring

For each point describe what Darwin meant, what evolutionists today believe, and how creationists would respond.

2. There is little factual evidence for the progression claimed by evolutionists; most is guesswork. Missing links are assumed, but none appear. Much information in the development has been omitted; those evidences which disprove the evolutionary process are ignored. (E.g., fossil records show that *Eohippus* and the horse existed simultaneously.)
3. **(1)** Theory of need–In order for an organism to develop a structure, it must need the structure. If it needs a structure, it will develop one. **(2)** Theory of use and disuse–If an organ is used by an organism, the organ will continue to evolve. An organ will degenerate if the organism stops using it. **(3)** Theory of inheritance of acquired characteristics–If an organism acquires characteristics, these traits will be passed on to its offspring.
4. Need has never been observed to influence the development of a characteristic in an organism; even if it did, it would not affect the genetic structure of the organism, and therefore could not affect the offspring. Also, if the organism needed a certain characteristic very much, it probably would not survive long enough to develop the characteristic and reproduce. Similarly, the use or disuse of an organ does not affect the genes that determine the next generation's characteristics.

7C-3 *The finches Darwin observed on the Galápagos Islands* (left) *may have been the result of natural selection. But it is no more an example of evolution than are the varieties of pigeons obtained by selective breeding* (right). *No new characteristics have been formed; only "puddles of the gene pool" have been isolated.*

Probably the best-known animal from the area is the giant land tortoise, which can weigh over 500 lb. and live over 100 yr. Darwin recorded riding one of these turtles at "360 yards per hour."

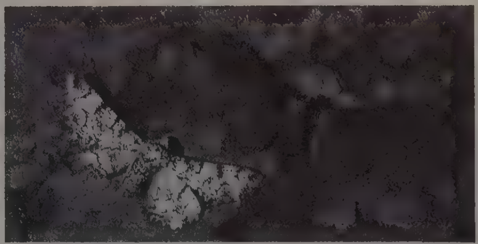
A group of birds Darwin observed reminded him of the finches he had seen in England and other parts of the world. Normally finches are seed-eaters. Some of the finches on the Galápagos Islands did eat seeds, but others fed on the fleshy parts of cacti. One group even used the spine of a cactus held in their beaks to obtain insects from under the surface of the cacti.

Darwin believed that all these various types of finches were descendants of a few finches which had migrated from South America, probably during a storm, and then had evolved to fit the various conditions they found in their new homes. Darwin used these observations to support his **theory of natural selection** and published it in 1859 in his book *The Origin of Species by Means of Natural Selection.*

Evolutionists are essentially saying, "Those that survive, survive," which is a tautology. In order to be logical, they must define "fittest" as something other than "survivor." Research indicates that organisms do not compete so as to exclude one another but to partition the resources so that all survive. The concept of competitive exclusion has not been supported by research.

Long before Darwin began his observations, scientists had recognized variations in organisms. Plant and animal breeders, for example, had practiced controlled breeding to obtain desired strains of existing variations. Literally dozens of varieties of pigeons, for example, have been bred from the wild rock pigeon. **Artificial selection** is man's choosing individual organisms to breed in order to obtain offspring with certain characteristics. Darwin proposed that the finches he observed, as well as other groups of organisms, had experienced the same type of breeding without man's help. Darwin's theory of **natural selection** is a major tenet of evolutionary theory.

An often-repeated modern example of natural selection involves the peppered moth and a change in its environment. About 100 yr. ago collections of the peppered moth made near London contained about 99% light-colored moths and 1% dark moths. At that time the trees around London were covered with a light-colored lichen. Light-colored moths resting on these trees were difficult to see and were therefore not eaten as



7C-4 *The change in populations of peppered moths in response to the industrial revolution is often cited as a proof of Darwin's theory of evolution. But is it?*

often by birds. Dark-colored moths, on the other hand, were easy prey.

The Industrial Revolution in England, however, so polluted the air that the lichen on the trees near London died, leaving the darker-colored bark exposed. The darker moths were therefore hidden, and the lighter moths were now exposed. In time, collections of the peppered moth began to show larger percentages of dark moths. At one time nearly 99% were dark-colored. Pollution controls in England, however, have permitted the lichen to grow again, and as expected, more recent collections of peppered moths show larger percentages of light-colored moths.

The Effects of Darwin's Theories

Darwin's support of the inheritance of acquired characteristics and improvement through struggle was just what many of the people of his day wanted. In fact, a contemporary of Darwin, Karl Marx, was so in favor of these evolutionary concepts that he wanted to dedicate his communistic work, *Das Kapital,* to Darwin. Darwin's theories are compatible with communism, which teaches that through collective effort man can improve his existence. Because it supported communistic philosophy, Lamarck's concept of the inheritance of acquired characteristics was until recently officially supported by the Russian government.

Darwin's theories have been used to support **environmental determinism,** the concept that the environment determines what an individual is. The concept blames the world around a person for the sin he commits. According to environmental determinism, a drunkard is not a *sinner* because he drinks but a *victim* of his environment; his environment drove him to drink.

The Christian view of man–that man was created perfect but is now a wicked sinner who is responsible for his sin–is by comparison unappealing. The Bible places the blame for sin on the individual. It says that man cannot save himself but is in need of the Saviour.

Darwinian evolution promises great things in the future if man *works* at it. Darwinism is, therefore, contrary to God and His Word in that it blames natural causes for man's present state and hopes in natural causes for man's future. In contrast, the Bible blames man for his condition and presents God as man's only hope.

Analysis of Darwin's theory

The peppered moth illustrates evolution no more than do the different types of cows, sheep, chickens, or corn. The peppered moth gene pool contains (and apparently has, since man first noticed them, contained) the genes to produce dark-colored individuals. Dark moths, however, were naturally "selected against" in an area of England. When an environmental change came, the dark moths were favored by the selection process. Nothing *new* was made. The change of frequency of a characteristic in a population is not biological evolution. A more complex organism has not developed. Biological evolution requires *new* characteristics, not just a regrouping of existing characteristics.

Almost every population of organisms has natural variations. According to Darwin, organisms struggle with one another to find food, shelter, and other necessities of life, because there is always overpopulation. The individuals having the best characteristics for success in the struggle are the ones to survive, reproduce, and pass their characteristics on to the next generation. Darwin called this principle the **survival of the fittest.**

The natural selection of the fittest organisms appears to be quite logical. It has drawbacks, however. First of all, there is not always overpopulation. Some organisms, like predatory birds, have behavior patterns in life cycles which prevent overpopulation. When there is a scarcity of food, these parents permit fewer young to develop so that there will not be overpopulation.

Another drawback to Darwin's "survival of the fittest" is that in nature, it is not always the fittest which reproduce. For example, an animal that can run fast and thereby escape predators may be considered the fittest. If, however, the sets of genes that cause its running ability also cut down on its reproductive ability, the "fittest" may survive, but it may not reproduce.

Consider what would happen if speed were genetically attached to lower intelligence, poor digestion, susceptibility to disease, or other inheritable disorders. Although the organism has particular genes enabling it to survive certain

This box contains supplemental material which should be read by most students. It explains why Darwinism caught on (see the philosophy of evolution, pp. 170-72).

For many years banana plants were grown in Moscow in the hopes that they would learn to survive and bear fruit despite the climate. The Lamarckian theory supported the idea that they would develop this characteristic if they "needed to."

environmental conditions, it may have other undesirable genes. In other words, the *best* all-around organisms are not always the ones to survive, nor are they always the ones to reproduce. Evolutionists, of course, define ''fittest'' as those that survive regardless of their qualifications and thus would not recognize this argument.

Survival of the fittest is not a method of developing new characteristics. It works by simply selecting for or against characteristics that already exist. A *method of variation,* a way to develop new characteristics, is essential to a theory of biological evolution. Another part of Darwin's theory attempted to explain how variations occur. Darwin believed that each organ of the body produces *pangenes,* which travel through the blood to the reproductive organs to be given to the offspring. These pangenes, Darwin thought, are affected by the organ where they originate and therefore result in the inheritance of acquired characteristics. Darwin borrowed this concept from Lamarck but claimed it as his own.

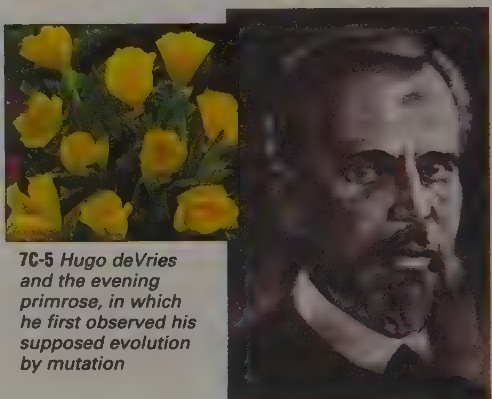
Today scientists consider the inheritance of acquired characteristics by pangenes to be an unacceptable theory. When introduced, however, Darwin's pangenes sounded interesting and scientific. The abundant examples of natural selection he gave in his works were accepted as adequate proof of pangenes. Examples of natural selection, however, have little to do with proving the inheritance of acquired characteristics through pangenes.

Review Questions 7C-2

1. Describe Darwin's theory of natural selection (survival of the fittest). What are some objections to this theory?
2. What mechanism did Darwin propose to supply variations for evolution? What are some objections to this mechanism?
3. Why is Darwinian evolution so compatible with environmental determinism?

Modern Evolutionary Theory

In the early 1900s a Dutch botanist, Hugo deVries, made some observations in his garden. He noticed various sudden changes, which he called *mutations,* in the offspring of an evening primrose, an American plant. In his book *Species and Varieties, Their Origin by Mutation,* deVries suggested that these sudden inheritable characteristics were the means of obtaining variations which could result in evolution. The characteristics which deVries observed, it was later learned, were nothing more than the sorting of characteristics already existing in evening primroses.



7C-5 *Hugo deVries and the evening primrose, in which he first observed his supposed evolution by mutation*

The concept that mutation supplies the variations and that natural selection decides which variations will survive and breed is called **Neo-Darwinism** or the **mutation-selection theory** and is accepted by most evolutionists today.

According to the mutation-selection theory, giraffes did not evolve because of a *need* to eat higher tree leaves. Some early short-necked giraffes just happened to have offspring with mutations which caused them to have longer necks. At the same time the long-neck mutations were happening, a drought began. The scarcity of food favored those giraffes with the longer necks, which could reach leaves on higher branches. They thus survived to breed and thereby passed on their long-necked genes, while the short-

The primary argument against biological evolution by mutation is statistical. Based on the odds, evolution could just not happen. Using a statistical approach, go through the material, stacking the odds higher and higher. This will help students see that although this is the only possible method of evolution, it could not be the method of evolving living things.

Mutations are well-known phenomena which were discussed in Chapter 6. Some evolutionists believe that the changes that result from polyploidy are evolutionary. Most chromosome changes which greatly affect the offspring (like polyploidy) are genetic dead ends in that they produce sterile offspring and require asexual reproduction to multiply. Unless a change can be passed on to offspring by sexual reproduction, it cannot result in evolution.

Those polyploids that do reproduce sexually, it should be noted, have still not evolved. Their genes are not new; the polyploid condition is merely a reshuffling or piling up of existing genes. Polyploidy appears to work to only a limited degree in the plant kingdom and a few other organisms.

Answers–Review Questions 7C-2

1. Organisms compete for food and shelter. Because there is always overpopulation, evolution states that the organisms with the best and strongest characteristics will be the ones to survive, reproduce, and pass on their desirable traits. Some objections to this theory are that there is not always overpopulation; it is not always the fittest that reproduce; natural selection does not prove inheritance of traits acquired. Darwin's theory about pangenes is unacceptable.
2. Pangenes, which are affected by the organ from which they originate, travel through the blood to the reproductive organs to be given to offspring, resulting in inheritance of acquired characteristics. Some objections to this mechanism include the following: natural selection does not prove inheritance of acquired characteristics through pangenes; the fit organism is ''born'' that way; there is no observable evidence to support even the existence of pangenes.

*3. A major tenet of Darwinian evolution is inheritance by pangenes. Pangenes are affected by the environment. If the environment is improved, the organism is able to evolve into a better organism. That the environment determines the quality (good or bad) is environmental determinism.

*From a box.

necked giraffes were unfit and therefore died without breeding.

Woe be unto the adolescent giraffe, not considered by the evolutionist: it was too old for mother's milk but not yet tall enough to reach the treetop-eating advantage of its inherited long-necked genes. The natural selection caused by the drought could easily be its premature undoing and eliminate the evolving species.

Mutations and evolution

For evolution to occur, new genes must form and enter the gene pool. A gene mutation is the only known method that could form new genes in nature. Gene mutations, however, are random. Although scientists can increase the rate of mutations, they cannot direct which genes will mutate.

Some scientists estimate that genes mutate once in ten million cell divisions. In a large population (say a billion individuals) the possibility of having a number of mutant genes is rather high. The necessity that these mutations be in the reproductive cells (germ mutations) and that they produce fertile offspring, however, limits the possibility of many mutations affecting the gene pool. The problem of the mutation-selection theory is not that mutations cannot occur. The problem is the accumulation of millions of related "good mutations" in one line of organisms. A "good mutation" is one that leads to the development of a workable new gene–if such a thing is even possible.

The odds of flipping two coins and having both of them land heads up is the product of multiplying the odds of getting heads up with one coin by the odds of getting heads up with the other coin. Assume that, when flipped, a coin lands heads up 1/2 of the time. If you flip two coins at the same time, the odds of getting heads up on both coins is 1/2 times 1/2, or 1/4. In fact, the more times the two coins are flipped, the more likely both coins will show heads 1/4 of the time.

If the odds of a mutation happening are 1 in 10 million cell divisions, the odds of 2 mutations happening to 1 gene are 1 in 100 trillion cell divisions. The question, then, is this: How many mutations are necessary for evolution? To take an existing gene and make it into another gene may

anthropology: anthropo- (Gk. ANTHROPOS, man) + -logy (the study of)

FACETS OF BIOLOGY

7C-1

Anthropology

Anthropology* (AN thruh PAHL uh jee) is the study of the origin and of the physical, social, and cultural history of man. Evolutionists for over 100 yr. have vainly searched for the "missing link" that would tie man to his animal ancestors.

Many times man's history has been "traced" from before the monkey to the present. Rarely do two evolutionists ever agree on this history which is often based not on concrete evidence but on the evolutionist's wishes.

"Human" missing links fall into four categories:

- **Human** Bones or complete skeletons that are like humans living today.
- **Animal** Bones or complete skeletons that are like extinct or living animals (usually monkeys or apes).
- **Insufficient data** Bone fragments so small that valid conclusions cannot be drawn from them. Sometimes a few bone fragments or a tooth are found, and with plaster and imagination, a manlike creature is created. Many supposed "fossil men" should be ignored because there is insufficient data to support their existence.
- **Hoax** Bones that have been tampered with. Occasionally a person wanting recognition as the finder of a fossil man or a person playing a joke has created "human fossils."

On pages 200-202 is a line-up of some of the better-known "fossil men." They are arranged from most apelike to those for which there is insufficient data or are hoaxes to those which are assumed to be from extinct tribes or people as human as any person alive today.

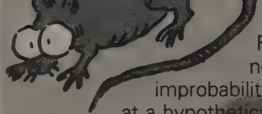
Review questions on page 207.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents that so-called "fossil men" are either like modern humans or like animals, not missing links.

The term **anthropology** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes. Consider having the students know the fossil men by name.

This box contains supplemental materials which illustrate the chapter content. It is suggested that all students read the box and that the instructor cover it in class.

Another suggested example is comparing a lizard scale to a feather. How many mutations are needed to go from a flat, relatively structureless scale to a highly structured feather? Getting the right kind and size of feather in the right place on the animal would require many mutations and many "weird lizards." Even the transition from a normal lizard to a winged reptile (see *Pteranodon,* p. 415) would result in some strange lizards that would have as much difficulty as the "brats" in staying alive.



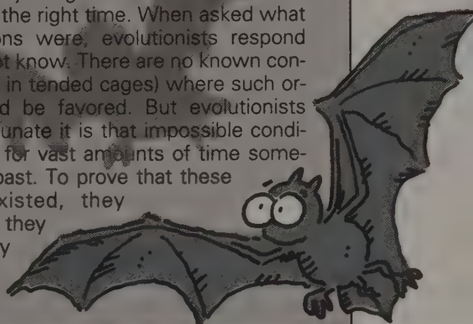
Rats to Bats–Mutations and Missing Links

For a moment let us ignore the gross statistical improbability of evolution and look at a hypothetical example (but, according to evolutionists, a true example) of evolution. Most evolutionists agree that the bat evolved from the rat (or a ratlike organism). Since rat and bat bodies are quite similar, many rat genes would not need to mutate in order to form a bat. But, of course, a lot of them would. But what about halfway organisms, the ones with becoming-bat mutations, which cause the organism to be neither rat nor bat? We shall call these *missing links* "brats."

Assume that a mutation occurs which causes a rat to have webbed toes. This is the first brat. This web-toed mutation needs to spread through many generations into a population of thousands, or even millions, of brats before another favorable rat-to-bat mutation can be expected. When it does come (probably many years later), it causes web-toed brats to develop front toes twice their usual length, making the second brat. Again, a sizable population must be developed to be ready for the next mutation.

In time, however, we will have brats with large webbed feet suitable neither for running nor for flying. Where do these brats live? How do they move? What do they eat? How do they protect themselves from predators? A large population of these organisms is necessary for the next favorable mutation to have a chance to occur. If evolution is true, these brats must have existed. But how? Natural selection is against the halfway brat's surviving long enough to become the next level of brat. Besides wings, these brats must also be evolving other bat characteristics, some of which (like a radarlike device for flying in the dark) are very complicated.

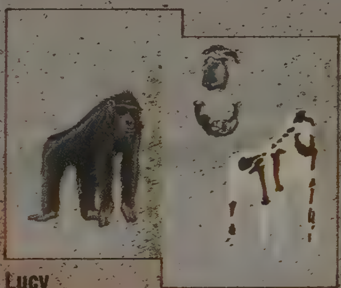
Evolutionists say that somehow, somewhere, conditions were just right for all the levels of brat to exist at just the right time. When asked what these conditions were, evolutionists respond that they do not know. There are no known conditions (except in tended cages) where such organisms would be favored. But evolutionists claim how fortunate it is that impossible conditions did exist for vast amounts of time somewhere in the past. To prove that these conditions existed, they point out that they were necessary for the bat to develop.



It is suggested that students be expected to recognize which category each of these "fossil men" falls into for testing purposes.

Australopithecus ("southern apes")

This organism supposedly lived 1,750,000-500,000 yr. ago and had a brain size of modern apes and monkeys (435-635 cc).



Lucy

Bones of a 3- to 3.5-foot-tall female organism with an unusual V-shaped jaw and long arms were found in Africa in the mid-1970s. This was probably an ape or monkey that walked on its hind feet. Some evolutionists believe Lucy was not a human ancestor, but rather an extinct organism.

Homo habilis

Known as the "handy man," this relic was found in Africa, but additional evidence is very fragmentary. It is possibly a female or young gorilla. It was called "handy man" because an object thought to have been a tool was found near some skeleton fragments.

Zinjanthropus

The first one of these was found in Africa in the late 1950s. The skull is exceptionally similar to the skull of a modern great ape. Other later finds are very similar. Evolutionists today admit that this was not a human ancestor but was actually an ape.

7C-6 *The possibility of an organism's evolving by mutation has been compared to taking all the parts of a skyscraper up one mile, dropping them, and having the building assemble itself on the way down.*

require hundreds of gene mutations. Surely the number of mutations necessary to go from one type of organism to another must be in the hundreds of thousands, millions, or billions. Julian Huxley, a famous evolutionist, admitted:

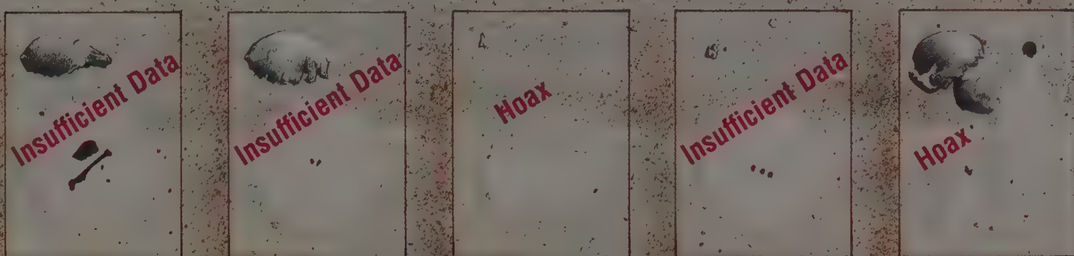
> One with three million noughts [zeros] after it is the measure of the unlikeliness of a horse–the odds against it happening at all. No one would bet on anything so improbable happening; and yet it *has* happened.

Evolutionists, seeing billions of years in the earth's history, have been able to say, "In *that* length of time *anything* could have happened." Yet evidence has shown that with billions of years, biological evolution could not occur.

Some people have compared the possibility of biological evolution happening to the possibility of a monkey at a typewriter randomly hitting keys and, in time, typing out the complete works of Shakespeare. According to evolutionary thought, if we give the monkey enough time, he just might be able to do it. Recently a man used a computer to determine how long it would take 1 trillion monkeys at 1 trillion typewriters, randomly typing 10 keys per second to type "To be or not to be: that is the question." His answer was that it

Point out that mutations do happen but that they are random departures from the order and design observable in the genetic make-up of organisms. The problem for an evolutionist is to have the millions of *good* mutations in a single line of organisms that would be necessary for evolution. Mutations generally destroy the useful information content of the genes in which they occur. Genetic engineering could change that–making man the "evolver" as well as the possible "evolvee."

Homo erectus ("erect man") This organism supposedly lived 500,000-300,000 yr. ago with a brain size of 700-1,100 cc (slightly smaller than modern man).



Java man
Bone fragments of a skull top, some teeth, and a thigh bone were found scattered over a 15-20 m stretch of a river bank. Based on what has been found, Java man could be anything.

Peking man
Plaster casts are all that remain of these lost bone fragments. There is disagreement regarding their authenticity. This is a possible hoax; skeletons of modern man and animals were in the same area.

Nebraska man
A tooth found in Nebraska received recognition as a fossil man until another group of scientists found more of the skeleton. The tooth came from an extinct pig.

Gigantopithecus
Teeth purchased through apothecary shops in the Orient were mixed with a great deal of plaster of Paris and lots of imagination and became an 8-ft. man. More teeth were "found," but that is all that exists of this race.

Piltdown man
As a prank, the jawbon of a chimpanzee wa filed down, treated wit chemicals, and the planted in an area wher scientists were going t dig. From 1912-1953 th Piltdown man was an ac cepted "fossil man."

will take more than a trillion times the evolutionists' estimated age of the universe to get this one Shakespearian line from the monkeys.

The possibility of evolution has also been compared to the possibility of a printed, bound dictionary resulting from an explosion in a print shop. Is such really possible? Yes, but would it ever happen? Even if the calamity happened every minute for 4 1/2 billion years, it is statistically impossible for a dictionary to have formed under such circumstances. The same is true of evolution by mutations.

The harmful nature of mutations

A mutation must alter an existing gene. Since gene mutations are random, happening in any gene, the vast majority of mutations are harmful. They often result in deformity because they change the gene for a needed characteristic. A *random* change in a highly organized system (and life's genetic code is probably the single most highly organized system known) will be a change toward disorder.

You could compare a mutation to randomly selecting one letter in one word on this page and changing it to a letter or puncuation mark that was also randomly selected. The chances of introducing a spelling or grammatical error are very high. Such an error would be considered harmful to the meaning of this page. The more random letter changes you make, the higher the probability of errors. Soon the page would contain many meaningless letter groups, and the meaning of this page would be lost.

Making even one random letter change per second it would take trillions of years before you could expect to have a page with no spelling errors on it, and it would be many times that long before you could expect to have a page that was error-free and made sense.

Those who believe in evolution by mutation are, in essence, contending that books can be rewritten to form other books by random letter replacements. New books are written by authors who carefully select letters to make words that have meaning when put together, not by randomly substituting letters in other books. The genetic material found in living things was designed by God, not by random substitution of nucleotides in the DNA of other living things.

Homo sapiens **("wise man")** The genus species of modern man contains several groups which are sometimes referred to as "fossil man."

Rhodesian man

These bone fragments are from a man about 5 ft. 10 in. tall. The apelike skull has some of the characteristics found only in humans. Some scientists believe that the skull does not belong with the other bones. Others suggest this individual had a hormonal disorder which even today causes people to have skulls with similar characteristics.

Neanderthal man

Many complete skeletons show that this group was essentially like modern man. Evolutionists claim that the Neanderthal people lived 75,000-30,000 yr. ago. Some people claim that most Neanderthal characteristics fit the Eskimo and the American Indian.

Cro-Magnon man

Many complete Cro-Magnon skeletons show that these people were essentially like modern man. They had wide cheek bones, deep-set eyes, and a square jaw, but would not be considered unusual if seen in a business suit today. Cro-Magnon men painted in caves, produced clay objects, and possibly worked in metal.

7C-2 FACETS OF BIOLOGY

Arguments That Have Been Used to Support Evolutionary Theory

In times past some evolutionists have used certain "scientific observations" to "prove" evolution. For a long time these arguments held significant sway, especially among nonscientists who were deceived by the words and scientific sound of the arguments. Additional observations and less biased conclusions deflate these impressive arguments.

Ontogeny recapitulates phylogeny

"Ontogeny* (ahn TAHJ uh nee) recapitulates phylogeny (fye LAHJ uh nee)," an impressive-sounding phrase, was at one time called the "biological law." It basically means that the development of an organism, its embryology (ontogeny), replays (recapitulates) its evolutionary ancestry (phylogeny).

In essence the **theory of recapitulation*** (REE kuh PICH uh LAY shun), as it is now called, says that when your zygote was formed, you were going through the single-celled organism stage of evolutionary development again. When the zygote divided a few times, you were recapitulating the colonial organism stage of your evolutionary past. Later you became a fish, a reptile, a mammal, and finally a human, at which point you were born.

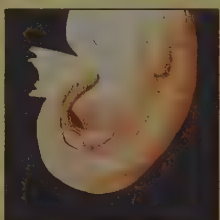
When a human zygote is formed, however, it has human genes, not monkey, reptile, fish, or ameba genes. A single human cell is a human cell, not an ameba cell. The only way a single cell can exist is to be like a single cell. This superficial likeness, though, does not mean it is related to other single cells. To become a fully developed human, an embryo must pass through various stages which may physically resemble other things.

Human Tails and Gills

Two structures in human embryos which have been listed in some textbooks as examples of recapitulation are the *human tail* and *gill slits.*

❑ *Human tail* Some of the first structures to develop in the human embryo are the parts of the nervous system. With the end of the spinal cord extending beyond where arm and leg buds are forming, it does appear as if the human embryo has a tail. In time past scientists believed that the tail disappeared, and that this supported the theory of recapitulation. Careful observations, however, reveal that as growth continues, the body catches up to the growth of the spinal cord. This development, not a disappearance of the "tail," changes the embryo's shape.

❑ *Gill slits* Fish and some other aquatic organisms have gill slits, which permit water to pass over the gills so that the organism can exchange oxygen and carbon dioxide between its blood and the water. Several folds develop alongside the human embryo's neck, and for a brief period the embryo appears to have slits between these folds. Actually there are no openings at these points, and there are no respiratory mechanisms (gills) inside them. These structures are not slits but folds and have nothing to do with gills. They are called gill slits only to support the evolutionary theory of recapitulation. In humans the folds grow together to become parts of the upper jaw, the lower jaw, and the upper chest.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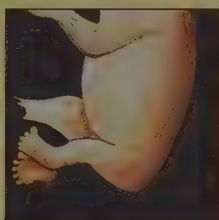
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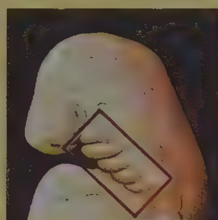
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9 weeks

ontogeny: onto- (Gk., ONTO, existing or being) + -geny, -gene, or genetic (GENEIA, birth)

recapitulation: re- (L. RE-, back or again) + -capitula- (CAPITULARE, to put under headings)

This Facet contains supplemental material which should be covered by most students. If time is limited, have students read the Facet, but skim the content in class. This Facet presents three arguments used by evolutionists (theory of recapitulation, vestigial structures, and homologous structures) and the creationists' answers to them.

The terms **theory of recapitulation, vestigial structures,** and **homologous structures** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Gill slits are also discussed on page 389.

vestigial: (L. VESTIGIUM, footprint)

The resemblance, however, proves nothing.

The theory of recapitulation has fallen from favor because evolutionists have had to admit that it is false. Occasionally, however, comparisons are still made between developing organisms. These comparisons prove only that developing embryos resemble one another; evolutionary relationships are not demonstrated by such comparisons.

The fact that a frog's liver appears and functions similar to a cat's liver does not show an ancestral relationship any more than the fact that a student's red hair makes him related to Thomas Jefferson, who also had red hair.

Vestigial structures

If evolution by mutation were true, we would expect to find **vestigial*** (veh STIJ ee uhl) **structures** in evolving organisms. A vestigial structure *(vestigial organ)* is one which no longer has a function. These are organs that supposedly were useful to ancestors but are now mutating away.

At one time the list of human vestigial structures had over 180 entries. Gradually scientists discovered that these structures do have functions. Indeed man cannot live without some of these structures once thought vestigial. Man can survive without others but functions best if he has them.

At present there are no structures in the human body that are believed to be vestigial. However, we do not know the function of many structures in plants and animals. It is safe to assume, though, that with further study scientists will discover that there are functions for these supposedly vestigial structures. Because of the intricate design of the creation, man can recognize that God is not a wasteful Creator.

Homologous structures

In science classes students can dissect certain animals to learn about human anatomy. Some animals have many structures in common with humans. Those organs that are similar in structure and func-

Go over this box quickly. These structures are studied in more detail as the human body is discussed (see Index).

Human Structures Once Considered Vestigial

Tonsils The tonsils are part of the body's defense against diseases. Occasionally the tonsils become overly infected (just as any part of the body can) and need to be removed. A good set of tonsils, however, is advantageous.

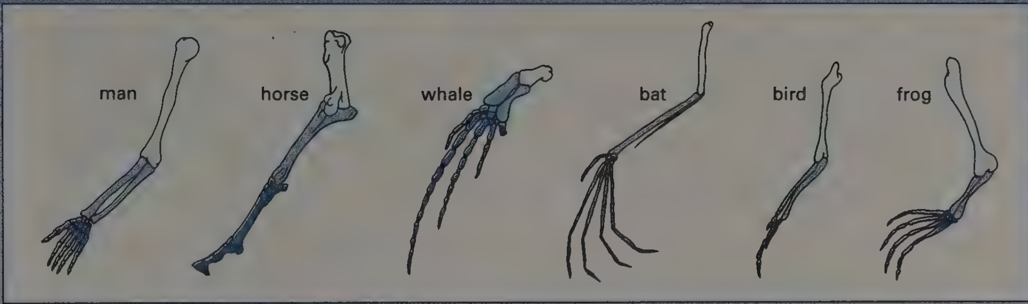
Coccyx (tail bone) The coccyx, a set of small, fused segments of backbone at the base of the spine, was once thought to be a vestigial tail. This tiny bone serves as a place of attachment for leg and lower back muscles.

Pituitary gland This gland was once thought to be either a degenerating or developing third eye because it is located under the brain, between where the two optic nerves leave the brain and go to the eye. The pituitary gland, however, produces many hormones that carefully regulate the body's metabolism. Without these hormones, a person would die.

Appendix This organ often becomes infected and must be removed. A person can function normally without it. Scientists now believe that the human appendix does function in digestion and in the body's defense against infection.

Thymus gland A mass of tissue in a child's chest that atrophies (goes away) as the person matures. The thymus gland is now known to produce antibodies and various cells involved with immunity to infectious diseases. Without it a child needs special medical attention to grow to adulthood.

The coccyx is illustrated on page 517. Most of these structures are discussed in more detail in the human anatomy and physiology section of the text (see Index).



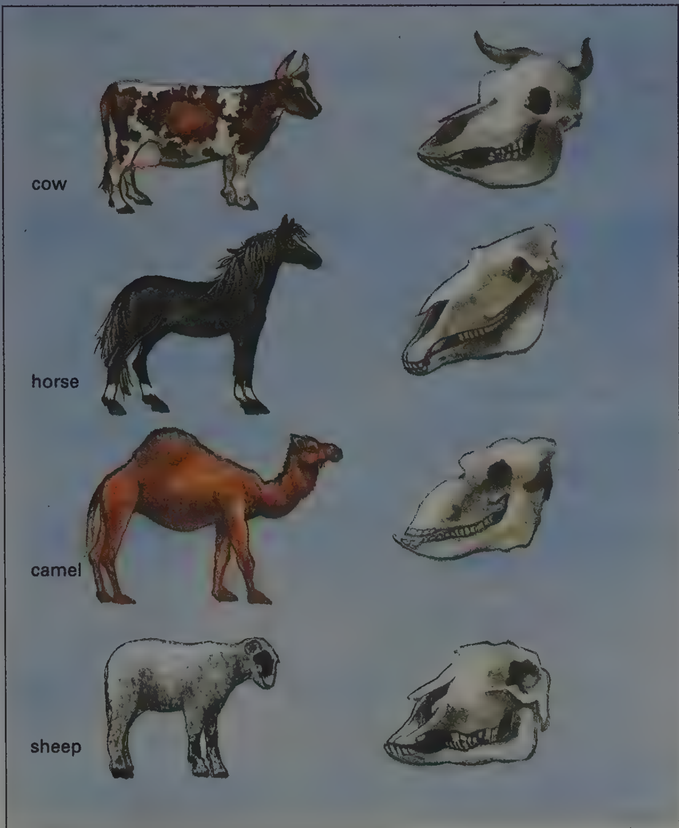
The homologous bones in the appendages of man and some animals tells little about how these organisms came into existence.

tion between two different organisms are called **homologous structures.**

Evolutionists assumed that if there were many homologous structures found in two organisms, they must be related by a common ancestor. Since a bird's wing and a whale's flipper have a similar number of bones and muscles which are used in movement, somewhere in their evolutionary past the bird and whale must be related. The observation of bones and muscles may be accurate, but the conclusion is based on bias. Seeing wheels on a car and on a roller skate would not cause one to think they came from the same factory.

The creation shows design. The whale's flipper works as well at moving the whale as the wing does at moving the bird. Some movements these appendages make are similar, some are not. The design is similar in relation to those movements that are similar and different in relation to those movements that are different.

Review questions on page 207.



The teeth of these animals are used for cutting and grinding. Similarity, however, does not imply a common ancestor.

Types of teeth seen in mammals are discussed on page 438.

Answers–Review Questions 7C-3 *(p. 207)*

1. Darwinism states that the need for a characteristic causes an organism to develop the characteristic in order to adapt to its environment. This characteristic is then passed on to offspring. The strongest organisms (those with desired traits) will survive and reproduce (natural selection). Neo-Darwinism states that changes occur in organisms due to sudden mutations, not needs. Those with mutations for a more desirable trait survive and reproduce (natural selection).
2. They occur only once in 10 million cell divisions and must occur in the repro-

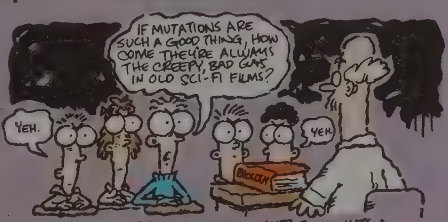
This box contains information regarding the harmful nature of mutations and should be covered by most students. Omit this box if time is limited. Is it possible that someone is seeking to change the image of mutations by having mutants be the "good guys" in some fantasy programs? Stress to students that mutations are harmful in that they randomly change the highly organized working genetic code.

Some evolutionary scientists have suggested that the sun has a small companion star called Nemesis. Nemesis is now about 2 light years away. In a few million years, it will turn and head back toward the sun. One orbit takes about 26 million years. These evolutionists speculate that every 26 million years there is a major earthly upheaval as Nemesis gets close enough to affect such things as comets and asteroids which fall to earth or to affect this planet in other ways. Thus, every 26 million years biological changes happen rapidly and then slow down. One such encounter with Nemesis resulted in the extinction of the dinosaurs; another wiped out the trilobites. Nemesis is the major moving part of "a great big clock in the sky [that] is controlling biological destinies on earth." *The Nemesis Affair* by David M. Rays, WW Norton and Company, New York, 1986, presents current speculations regarding Nemesis.

Observed Mutations–Expected Mutations

If evolution were to take place today, it would most likely be in an organism that has had an increased mutation rate and therefore opportunity to evolve by mutations. The fruit fly has been exposed to mutation-inducing chemicals and radiations for many years. Thousands of different mutant fruit flies have been produced. Few of these mutations, *if any*, could even possibly be considered helpful to the fruit fly. Most nonlethal mutations induced in fruit flies produce characteristics like curly wings, deformed eyes, or missing parts, which would quickly be eliminated by selection in nature.

A fruit fly can carry only a certain number of mutations. If evolution were true, organisms would have to be able to carry thousands of mutations which did not benefit the organism. The number of mutations an organism (or sometimes a gene pool) has is often referred to as its **genetic load.** Too much of a genetic load kills the organism. Since mutations are usually recessive to the allele from which they come, a light genetic load is counterbalanced in heterozygous individuals by normal alleles. If, however, the genetic load is too heavy, some homozygous individuals for the mutation develop. For this reason close inbreeding often produces an inferior stock



THE EVOLUTIONARY THEORY OF MUTATIONS HITS A SNAG WITH THIS PENETRATING QUESTION....

of organisms. Such organisms produce few offspring, many of which are deformed.

One might think that since evolutionists believe that mutations are the means whereby evolution takes place, they would encourage them to occur. The exact opposite is true. If a substance is shown to increase the mutation rate, scientists quickly speak against it. For example, many scientists believe that decreasing the ozone layer in our atmosphere would permit more of the sun's mutation-inducing radiation to come to earth. But scientists predict that diminishing the ozone layer would produce not the evolution of man into a super race, but rather thousands of new cases of cancer and other dire consequences.

Punctuated equilibrium

For years non-evolutionists have pointed out that there is no observable example of evolution happening today. Since Darwin's time, evolutionists have been able to answer that evolution is a long, slow process, and man has just not observed closely nor long enough to see evolution. In the hundred years since Darwin's death, scientists have been looking *very* carefully for an example of evolution. But there is no concrete, observable example of it happening today.

As evolutionists have recognized the problem, some have added a new twist to evolutionary theory: **punctuated equilibrium.** This is the belief that there were periods of time when evolution happened rapidly, followed by periods of time when almost no evolution took place.

In other words, there were times when, for unknown reasons, mutations and natural selection happened rapidly and organisms evolved. Then, for other unknown reasons, mutation rates and natural selection slowed, and evolution virtually ceased. According to these evolutionists, most organisms are in a non-evolutionary phase, which explains why there are no present examples of evolution. Some evolutionists try to explain missing links by saying that they appeared during a period of rapid evolution and quickly died off. Since they were not around long enough to have made fossils, they are truly missing, and we should not be concerned about finding them.

Because punctuated equilibrium seems to explain some of the arguments against evolution, some evolutionists have adopted it. This new twist, however, does not change the basic scientific arguments against evolution. Even when scientists have tried to make evolution happen in a laboratory by increasing the mutation rate (as they

ductive cells. All "good mutations" would have to occur in one line of organisms. Fertile offspring are essential.

*3. In order for evolution to occur, an organism would have to carry thousands of mutations; however, if the number of mutations (genetic load) were too heavy, this condition would kill the organism. A large number of mutations is not beneficial, as supposed by evolutionists. Thus, evolution through great numbers of mutations is not possible.
4. Punctuated equilibrium is the concept that evolution happens rapidly for a period of time, followed by long periods during which no major evolutionary changes take place. This is sometimes used to explain why evidence of evolution cannot be observed. The probability and means of evolution are not any greater because of punctuated equilibrium.

*From a box.

Answers–Facet 7C-1

1. **(1)** Human bones or complete skeletons; **(2)** animal bones or complete skeletons; **(3)** insufficient data; **(4)** hoax
2. **(1)** Human bones or complete skeletons–Neanderthal man, Cro-Magncn man; **(2)** animal bones or complete skeletons–*Zinjanthropus*, Lucy, *Homo habilis;* **(3)** insufficient data–*Gigantopithecus*, Java man, Peking man; **(4)** hoax (those that have been tampered with)–Piltdown man, Nebraska man

Answers–Facet 7C-2

1. **(1)** Human tail–Evolutionists believed that the tail disappeared as the embryo developed (thus supporting recapitulation); evidence now demonstrates that other tissues grow to obscure the tail. **(2)** Gill slits–Structures thought to be gill slits are only folds; they have nothing to do with gills or gill slits.

assume must have happened during the evolutionary periods), there has been no observable evolution.

Even with punctuated equilibrium, the statistical improbability of evolution is still great. Although mutations may occur rapidly, the possibility of "good mutations" and their coming together are not increased by punctuated equilibrium. Periodically increasing the rate at which evolution is supposed to have happened does not make evolutionary theory any more scientifically acceptable.

Creation shows design

One of the primary characteristics of the creation we observe is its universal design. Everything works together. A delicate balance exists between the organisms and the environments in which they are found. Substances are carefully recycled, and energy is carefully obtained and transferred in systems so efficient that man's best machines are poor copies. A look at the world we know speaks of an all-knowing, all-powerful Creator, not of the continuing disorder necessary for evolution.

When the scientific evidence is examined carefully, the creationist view is more acceptable than an evolutionary view. This is not surprising. The Bible's Author, after all, is the Creator. His record of life's origin would inevitably be correct. Since the world was designed and is sustained by God, what true science observes about the world reveals it as God's creation.

Biological Terms

phylogenetic tree
common ancestor
missing link

The Evolution of Evolutionary Theory
artificial selection
natural selection, theory of
environmental determinism
survival of the fittest

Modern Evolutionary Theory
Neo-Darwinism
(mutation-selection theory)
genetic load
punctuated equilibrium

Facets
anthropology
theory of recapitulation
vestigial structure
homologous structure

Review Questions 7C-3

Answers begin on page 205.

1. Describe the basic difference between Darwinism and Neo-Darwinism.
2. List several reasons that gene mutations could not be the means whereby evolution occurs.
3. In what way does the concept of a genetic load support the creationists' views?
4. Describe punctuated equilibrium. Tell why many evolutionists have adopted the theory. Give a creationist's answer to punctuated equilibrium as an evolutionary explanation.

Facet 7C-1: Anthropology, pages 199-202

1. What are the four categories that all supposed human fossils have fallen into?
2. List several fossil finds that fall into each of the four categories of supposed human fossils.

Facet 7C-2: Arguments That Have Been Used to Support Evolutionary Theory, pages 203-5

1. Give two structures often used to support the theory of recapitulation in humans. What are some objections to the use of these structures to support the theory of recapitulation?
2. Name several human structures that were once considered vestigial. Why are they no longer considered vestigial?
3. Briefly describe the evolutionary argument based on homologous structures. Explain why this argument is not valid.

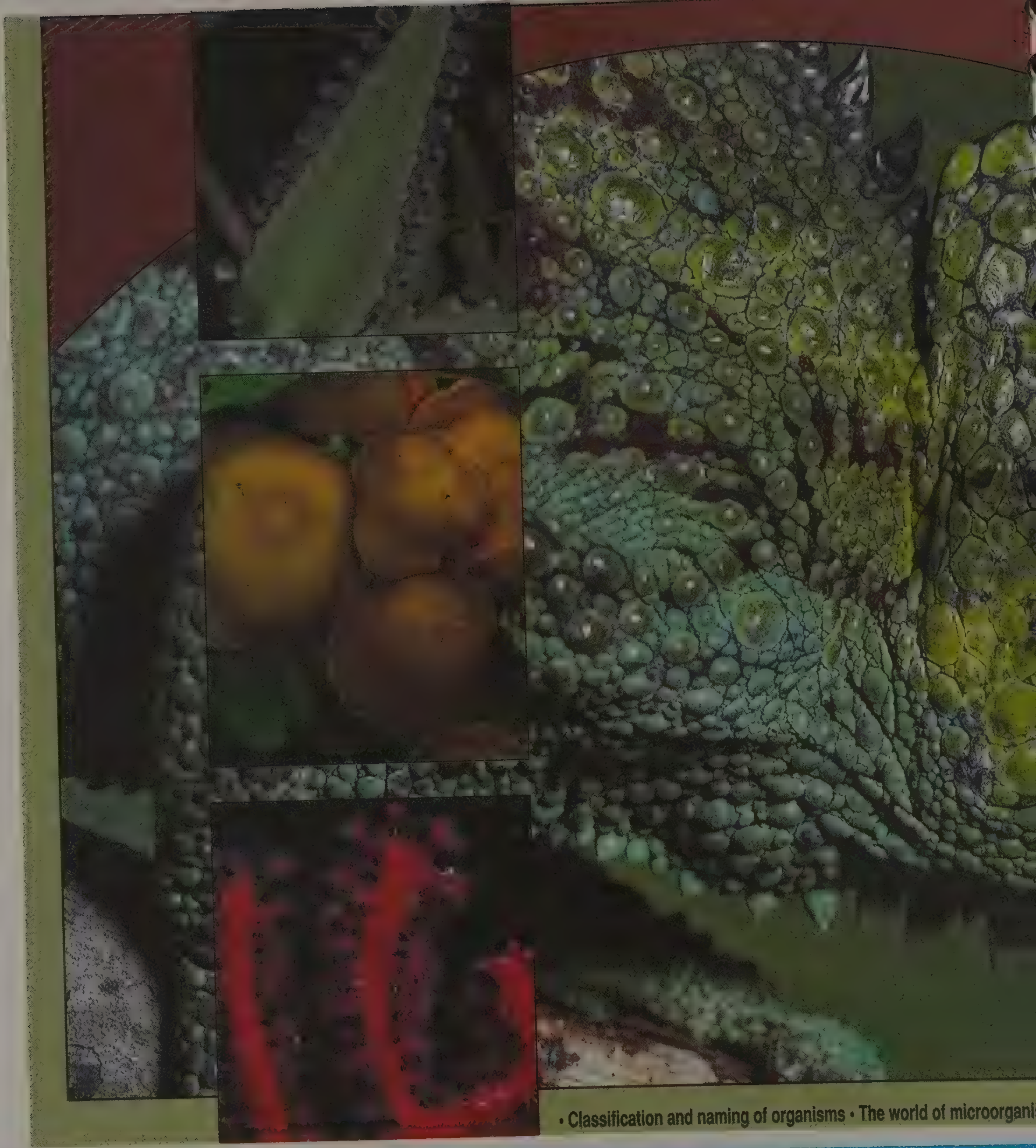
Thought Questions

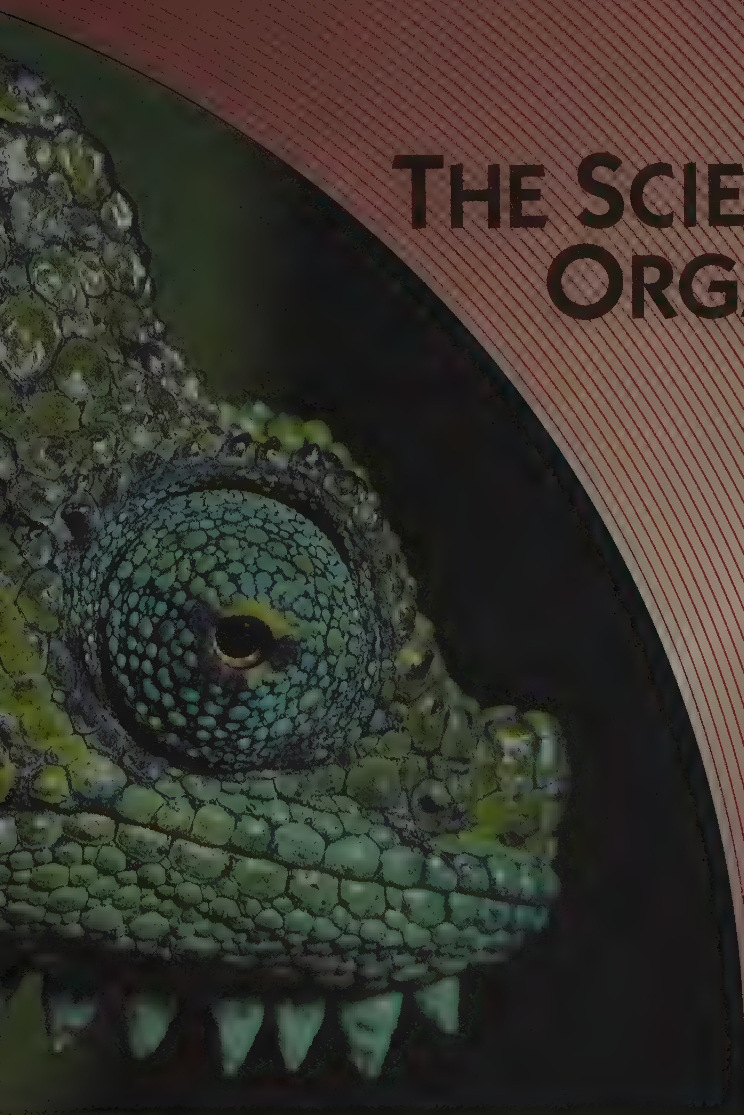
1. It has been said, "The world was ready for Darwin." Account for the popularity of the theory of evolution after Darwin.
2. Discuss the statement "Evolution by mutations and natural selection is possible, but improbable."
3. Compile a list entitled "Things Evolutionists Must Ignore to Believe Evolution."

2. The tonsils, coccyx (tail bone), pituitary gland, and appendix were once thought to be vestigial. They are now known to have necessary functions.
3. A homologous structure is one that is similar in structure and usually similar in function in different organisms. Evolutionists argue that homologous structures show common ancestry. Creationists argue that structural similarities can show a perfection of design and have nothing to do with common ancestors.

Answers–Thought Questions

1. Prior to Darwin, no one had written such a lengthy volume about evolution. Since many people were already skeptical about the Genesis account of creation and the Flood, they were susceptible to any ideas that supported their philosophy.
2. Traits can be introduced into an organism's gene pool only by mutations. Natural selection could work if there were past significant changes in the environment to make it suitable for the unusual variations that would be necessary if evolution were true. However, the improbability of those significant environmental changes and the statistical impossibility of having sufficient good mutations to cause the great variations necessary for biological evolution make such a process impossible.
3. Some examples are creation of the entire universe in six days; the Flood; all "out-of-place" fossils; all polystrate fossils; the unique balance of living and nonliving things of the earth; the uniqueness of humans; the limitations of science; the existence of God; future events described in Revelation.


• Classification and naming of organisms • The world of microorgani



II
THE SCIENCE OF ORGANISMS

fectious diseases, disorders, and death • Plant anatomy, growth, and reproduction • Animals without backbones

Time Frame
8A (with Facet): $1\frac{1}{2}$-2 periods
8B: 1 period

Laboratory Activity
8–*The Use of Biological Keys* involves students using a key to classify organisms. It can take an entire period, be reduced to a few minutes, or be used as an oral exercise.

EIGHT

THE CLASSIFICATION OF ORGANISMS

8A-The Necessity of Classifying

People group things together for convenience. All the spices in your mother's kitchen are probably in the same cabinet. At the same time, the pots are in one place, and the dishes are in another. Imagine the confusion you would create if you put spices and cooking utensils into the nearest empty space when you were finished using them.

When you think of musical instruments, you do not only think of them as individual instruments; you also put them into groups, such as woodwinds, strings, percussion, and brass. It is easy to put the violin, viola, cello, and string bass together in the string group. They look alike and are played in essentially the same way. Suppose someone speaks to you about the viola da gamba. When you look puzzled he tells you that the viola da gamba is an antiquated instrument in the string group. You then have a good idea of what type of an instrument it is because you are familiar with other members of the group.

Classifying musical instruments is not easy. The piano, harpsichord, and harp all have strings

8–The Classification of Organisms

During the writing of this text, many people asked "What are you going to do about the classification system?" Some people were concerned the author would do nothing. Others were concerned the author *would* do something. Some well-meaning people actually wanted a completely new "creationistic" classification system for all living things.

First of all, the project of introducing a new classification system is beyond the scope of a high school biology textbook. Many would agree that it is time for a new system; however, this is not the place to introduce it. Besides, this author is not qualified for such an endeavor.

Second, no matter how organisms are grouped for classification, the groups will be similar to those that now exist. Vertebrates, mammals, bacteria, and many other existing groups are relatively distinct. No matter what type of classification system is devised, these groups will probably appear in it. They may be at different levels (e.g., what is now called a phylum may be moved to the kingdom or class level), but they will probably survive any classification system changes. Most changes would be made in the smaller groups: families, genera, and species. In a high school biology survey, discussion centers upon the larger rather than smaller groups in which changes are constantly made.

Evolutionists try to use the classification system to prove evolution. They attempt to reclassify organisms to show relationships or ancestry. Little of this reclassification affects the larger groups, which are the ones studied in this course. Reclassifying the class Aves and the class Osteichthyes as phyla in the kingdom Vertebrata would do little or nothing to show relationships. The natural grouping of birds and fish still exists. The fact that some people

but are played very differently. Do they belong with the violin? The piano has strings which are struck, not plucked or stroked by a bow. Because of this, some think the piano belongs with the drum, xylophone, triangle, and other percussion instruments. Others think that since the piano has a keyboard, it should be grouped with keyboard instruments. Except for their keyboards, however, the piano and the organ have very little in common. Does the piano actually belong in *all* these groups? Maybe it should be classified by itself.

The same problems apply to **taxonomy*** (tak SAHN uh mee) (or **systematics**), the science of classifying organisms into groups. The taxonomist, however, has over a million different kinds of organisms to group, with 10,000 to 20,000 more being added each year.

Sometimes when a new organism is classified, so little is known about it that it is put in the wrong group. Occasionally, after learning more about a group of organisms, scientists decide to divide the group. At other times they expand the definition of a group to include several groups. The modern system of classification is flexible and useful, although it sometimes appears confusing because of its scope and flexibility.

Today's biological classification system suffers from many of the same problems as classifying the piano. But it does permit similar organisms to be put into groups so that the organisms and information about them can be dealt with conveniently. Were it not for a good classification system, most information about the organisms would be lost in a hodgepodge of facts.

The Classification Hierarchy

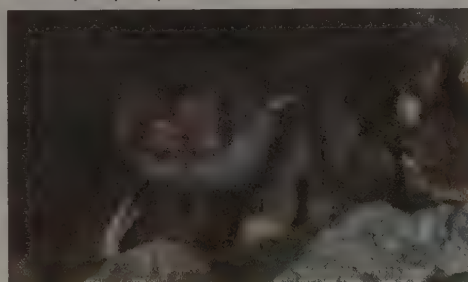
The first recorded classification of organisms was attempted by the Greek scientist and philosopher Aristotle. He classified living organisms into one of three plant or three animal groups. Plants were *herbs* if they lacked woody parts; *shrubs* if they had several short, woody stems; or *trees* if they had one large, woody stem. Animals were classified by where they lived: animals living in the water were *fish;* if they could fly, they were *birds;* those that lived on land were *land animals*.

Because Aristotle's six groups were based on appearance, his system is called an **artificial classification system**–one which is based primarily on observable characteristics. In Aristotle's system the lobster and the tuna are both fish, even though the lobster has more physical characteristics in common with insects, which are land animals. Are butterflies land animals or birds? Surely they are more like the flightless insects than they are like robins or hawks.

Whenever physical characteristics are used for classification of the organisms, there will be either useless generalities–"*most* organisms that fly are birds, *most* that swim are fish"–or many exceptions–"birds include all flying organisms *except* butterflies, flies, and bats."

Although Aristotle's artificial classification system left much to be desired, it was used for almost 2,000 yr. The problems in Aristotle's system had long been recognized. In the mid-1700s, when Carolus Linnaeus (lih NEE us), a Swedish

8A-1 *In Aristotle's classification system the Mexican vampire bat (top) and the regal moth (bottom) would be birds since they both fly. The ability to fly is about the only way they are similar.*



taxonomy: tax- (Gk. TAXIS, arrangement) + -nomy (Gk. NOMOS, law)

Many students find taxonomy confusing with all the big names! By first explaining the need for classification and then briefly tracing its history, the students' interest in learning the classification system can be sparked.

One way to help students understand the concept of classification is to have several identical collections of screws, nuts, bolts, thumb tacks, and nails for various students to classify. Then ask for justification of their groupings. Their reasons will be characteristics. Emphasize that this is the same method scientists use to classify organisms.

Students should learn in order the seven basic levels of the classification system.

Man's physical body is classified by scientists in the following manner:

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Order:	Primates
Family:	Hominidae
Genus:	*Homo*
Species:	*sapiens*

It is recommended, however, that man be treated as a special creation of God, as is indicated in Genesis 1 and 2. The need to classify man does not really exist. It is suggested that teachers cultivate the phrase "animals and man" and "mammals and man" in order to separate man from animals.

misuse classifications is not a good reason to abandon the study of birds or fish as groups.

The text stresses that the classification system is composed of manmade groupings used for convenience. This tool aids man's understanding of the vast number and variety of living things. If this is kept in mind, the study of the systematics takes on a new light. First, any evolutionary significance attributed to it becomes man's bias. Second, the need for classification groups becomes obvious. When students see that need, they are more inclined to accept the study.

Since the first edition of this text, there have been several changes in the generally used taxonomical system. Those changes are reflected in this edition, but because of the general nature of this chapter, they are not apparent here. Those familiar with the old text will see the changes in later chapters, especially Chapters 9 (bacteria), 11 (fungi), and 12 (plants).

In this edition of the text, the characteristics and classification tables that were scattered through the previous edition have been collected and organized in *A Modern Classification System* (Appendix B, pp. 652-65). This is a listing of major classification divisions along with major characteristics. Some classification divisions are only listed (with a few examples but no characteristics). Those groups which are presented in the text have the major characteristics listed in Appendix B. In other words, this back-of-the-book chart should be useful to students for summary, review, or study purposes. It is suggested that students be introduced to this appendix during this chapter.

8A–The Necessity of Classifying

Notes–Chapter 8A

Students are often turned off by the long names associated with classification. Most "big names" are unnecessary for most

phylum: (race or class)

Students should not memorize the phyla, subphyla, classes, and orders presented in this diagram at this time. This diagram is merely to show how groups are broken up into smaller groups. Students should note how the characteristics of a larger group (e.g., phylum) apply to all of its subgroups.

Visual 8A-1 can be used to teach the levels of the classification hierarchy. Using a second transparency or the acetate roll of the overhead projector, use pens to illustrate some of the examples given below.

Strep throat bacterium

K–Monera
P–Schizophyta
C–Schizomycetes
O–Eubacterials
F–Lactobacillacea
G–*Streptococcus*
S–*pyogenes*

Paramecium

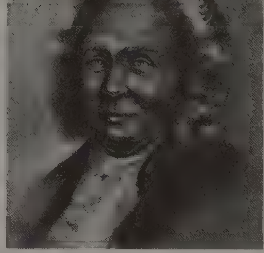
K–Protista
P–Ciliophora
C–Ciliata
O–Hymenostomatida
F–Parameciidae
G–*Paramecium*
S–*caudatum*

Maidenhair fern

K–Plantae
P–Pterophyta
C–Filicineae
O–Filicales
F–Polypoiaceae
G–*Adiantum*
S–*pedatum*

Wild rose

K–Plantae
P–Anthophyta
C–Dicotyledoneae
O–Rosales ▶



8A-2 In the 1700s, Carolus Linnaeus (right) proposed the classification system we use today. A few levels, characteristics, and examples of the Kingdom Animalia are given. Linnaeus established a system of scientific naming of organisms. He believed that his species level was the same as the Biblical kind.

KINGDOM ANIMALIA
1. heterotrophic
2. multicellular

- **Phylum Arthropoda** 1. exoskeleton 2. jointed legs
  - **Class Chilopoda** 1. head and many body segments 2. one pair of legs per segment
  - **Class Arachnida** 1. two body divisions 2. four pairs of legs
  - **Class Insecta** 1. three body divisions 2. three pairs of legs
    - **Order Orthoptera** 1. chewing mouth parts 2. heavy front wing, thin hind wing
    - **Order Diptera** 1. sucking mouth parts 2. two pairs of thin wings
    - **Order Lepidoptera** 1. sucking mouth parts 2. scaled wings
- **Phylum Chordata** 1. internal notochord for support 2. hollow dorsal nerve chord
  - **Subphylum Cephalochordata** 1. keeps notochord 2. gills slits for respiration
  - **Subphylum Vertebrata** 1. notochord replaced by a vertebral column 2. usually two pairs of appendages
    - **Class Osteichthytes** 1. fins and scales 2. two-chambered heart
    - **Class Amphibia** 1. smooth, moist skin 2. two-chambered heart that becomes three-chambered when adult
    - **Class Aves** 1. feathers 2. four-chambered heart
    - **Class Mammalia** 1. hair (fur) 2. four-chambered heart
      - **Order Rodentia** 1. two sets of incisor teeth 2. rotating elbow
      - **Order Carnivora** 1. claws 2. small incisor teeth, large canine teeth

naturalist, set forth a new classification system in his works *Species Plantarum* and *Systema Naturae,* scholars of the time readily adopted it.

The Linnaean system is also an artificial classification system. Yet because it has more flexibility than previous systems, the Linnaean categories and system of naming organisms are still used today, 200 yr. after their development. Scientists often recommend changes in the system. Some of these changes are accepted by international scientific committees which meet every few years to decide questions of taxonomy.

Today's system of classification

Taxonomists today use a classification hierarchy, an arrangement of graded levels. This system has seven basic levels as follows:

- ❑ **kingdom**
- ❑ **phylum*** (pl., *phyla,* technically called "division" in the kingdoms Plantae and Monera)
- ❑ **class**
- ❑ **order**
- ❑ **family**
- ❑ **genus** (pl., *genera*)
- ❑ **species**

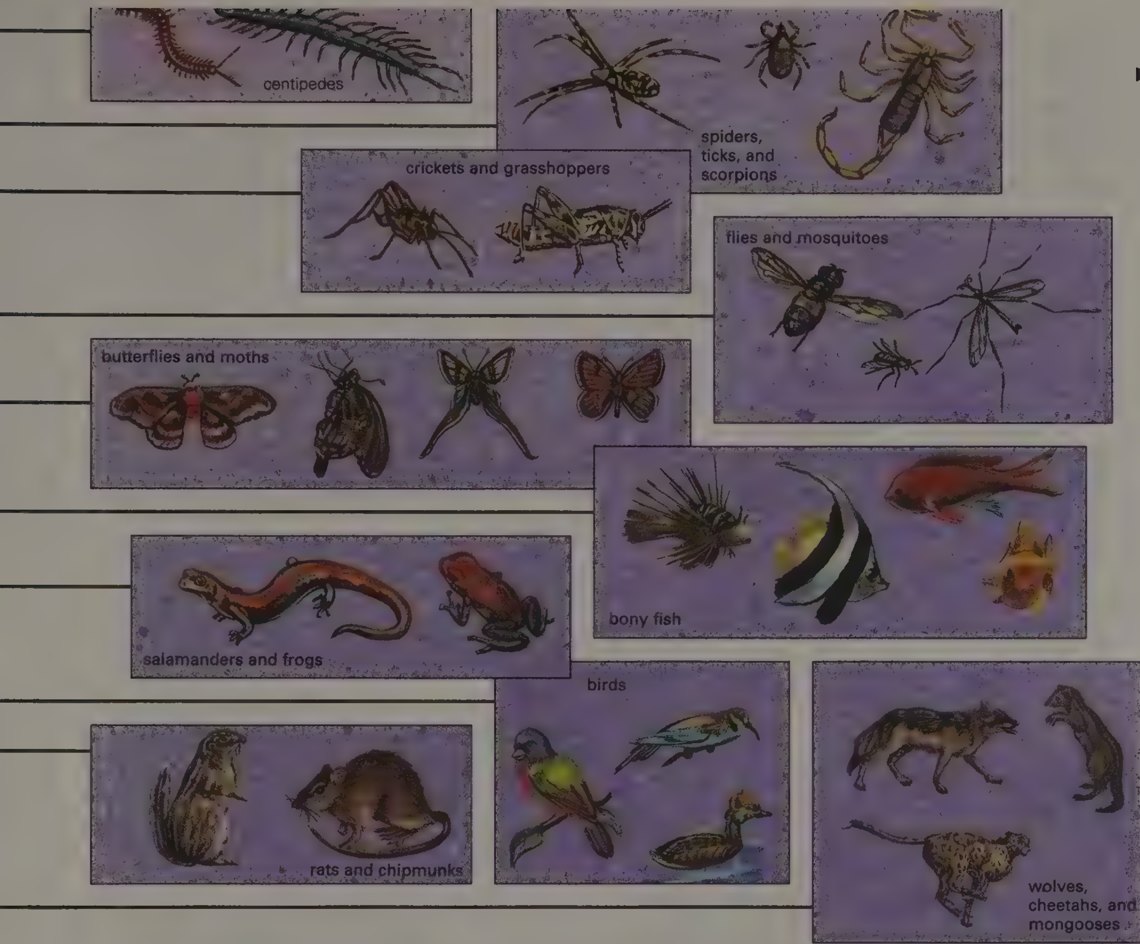
people. The idea of grouping organisms by characteristics, however, usually not only makes sense but also seems useful. The main thrust of the first part of this chapter is grouping organisms for convenience. "Big names" will come later.

Objectives–Chapter 8A

- ❑ Show the need for a biological classification system.
- ❑ Explain how scientific names are written and discuss the reasons scientific names are important.
- ❑ List the seven main levels in the current biological classification hierarchy and explain the descending hierarchy of the system.
- ❑ Describe the kingdoms Monera, Protista, Fungi, Plantae, and Animalia.
- ❑ List some problems involved in classifying living organisms.
- ❑ Demonstrate an understanding of the modern taxonomic system.
- *❑ Demonstrate how to use a simple biological key.

*From a Facet.

Once students see the need for groups, the five kingdoms should be presented. Two of the five (Plantae and Animalia) should be very simple. Fungi can be discussed quickly. That leaves only two to "learn." The problem is learning characteristics, not examples. One good way to do this is to deal with a few hypothetical unknowns. For example, "We find 'this' but don't know what it is. The first step is to find out what group (kingdom) it is in and then go on." Or "A friend tells you about some organism you are not familiar with. You ask what group (kingdom) it's



▶ F–Rosaceae
G–*Rosa*
S–*virginiana*

Hair cap moss

K–Plantae
P–Bryophyta
C–Musci
O–Bryales
F–Polytrichaceae
G–*Polytrichum*
S–*commune*

Two-striped grasshopper

K–Animalia
P–Arthropoda
C–Insecta
O–Orthoptera
F–Acrididae
G–*Melanoplus*
S–*bivittatus*

American alligator

K–Animalia
P–Chordata
C–Reptilia
O–Crocodilia
F–Alligatoridae
G–*Alligator*
S-*mississippiensis*

Use these as examples of how the system works, not as material to memorize.

A few of the taxonomic levels in the animal kingdom and a few characteristics for each level are given in chart 8A-2. This table can be used to illustrate the following general rules for using the biological classification hierarchy:

❑ *Each group on one level of the hierarchy may be divided into several groups on the next lower level.* For example, the kingdom Animalia is divided into about twenty phyla (only two are shown in the chart). Each phylum is divided into several classes, the next lowest level; each class is divided into several orders; and so on.

❑ *Each group in the hierarchy has various characteristics that all of the levels under the group possess.* For example, the phylum Arthropoda, according to the chart, contains organisms that have an exoskeleton and jointed legs. Exceptions do exist, however, especially when a classification listing is being simplified. The caption under subphylum Vertebrata reads, "usually has two pairs of appendages." An obvious exception is a snake. Because this is an artificial classification system, terms such as *usually* and *most* appear often.

Students should learn these general rules for using the biological classification hierarchy.

in, and then you know a little about it." At this point students should be expected to know only general characteristics of each kingdom.

This would be an excellent time to introduce students to Appendix B (pp. 652-65). Tell them that they will be using it as they progress through the book, but they will not have to learn all of the appendix–most of it, maybe, but not *all* of it. (Smile very broadly after saying this!)

The second part of the chapter deals with scientific names. The importance of scientific names is made clear in the text. Tell students that they will not be responsible for scientific names unless they are the only names the organisms have (e.g., *Paramecia, Nostoc*) or unless you tell them that the names will appear on the test.

Facet–Chapter 8A

The only Facet in this chapter deals with identification and the use of biological keys. Even if time is limited, be sure students know the difference between identification and classification. This differentiation is made in the first two paragraphs of the Facet. This Facet must be covered if students are doing the laboratory activities in this chapter.

❑ *Each level of the hierarchy can be divided into smaller units before reaching the next lower level.* For example, in the phylum Chordata there are *subphyla* which are divided into classes. Prefixes such as *sub-* (below), *infra-* (below), and *supra-* (above) are used to name these divisions.

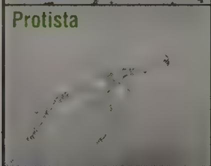
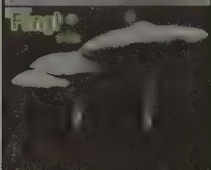
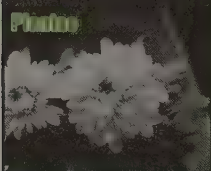
A complete listing of all the taxonomic levels, their characteristics, and all their organisms would be as large as an encyclopedia. A listing of the ones studied in this book and a few others can be found in Appendix B.

The kingdoms

Aristotle's classification system placed his six groups into two main divisions: plants and animals. Linnaeus also used two groups: "kingdom Plantae" and "kingdom Animalia." These two men, however, had no knowledge of microscopic organisms. Nor did they realize the vast difference in some of the groups such as the fungi. They neatly tucked fungi into their systems and, to a great extent, ignored them. Because more types of living things are now known and more

Students should be responsible for the material in 8A-3. Provided they understood Chapters 3 and 4, this will not be difficult.

8A-3 The Kingdoms and Their Characteristics

Kingdom	Cellular Structure	Colonies, Tissues, and Organs	Nutrition	Reproduction	Examples
Monera 	Lack organized nuclei and membrane-bound organelles. Most have cell walls and slime coats.	Often unicellular, but many form simple colonies; no tissues or organs.	Most are heterotrophic, some photosynthetic, or both. Some are chemosynthetic; some carry on only fermentation.	All reproduce asexually.	bacteria, cyanobacteria
Protista 	Have organized nuclei and membrane-bound organelles. Many have cell walls.	Unicellular or in colonies (some with specialized structures); no true tissues or organs.	Photosynthetic, heterotrophic, or both.	All reproduce asexually, but many can reproduce sexually by conjugation or gametes.	protozoans, algae (except blue-green)
Fungi 	Have organized nuclei and membrane-bound organelles. Many have cell walls.	Unicellular or in colonies (some with specialized structures); no true tissues or organs.	All heterotrophic, digesting food externally and then absorbing the nutrients.	All reproduce asexually, but most forms have sexual reproduction.	mushrooms, molds, yeasts
Plantae 	Have organized nuclei and membrane-bound organelles. Have cell walls made of cellulose. Have plastids.	All multicellular with tissues and organs.	Most are photosynthetic with chlorophyll *a*, some are heterotrophic, or both.	All reproduce sexually, but many have asexual forms of reproduction.	trees, ferns, flowers, grains
Animalia 	Have organized nuclei and membrane-bound organelles. Lack cell walls and plastids.	All multicellular with tissues and organs.	All are heterotrophic.	All reproduce sexually, but many have asexual forms of reproduction.	worms, sponges, insects, vertebrates

information about organisms is available, it has become necessary to recognize additional groups.

Most scientists agree that two kingdoms are not enough. Yet the international committees responsible for classification have not agreed on the exact number that should be established. The five-kingdom system is increasingly being accepted as the best because its groups are more useful than those of any other system.

It is easy to see the difference between the **kingdom Monera** (moh NEHR uh) and the others. Being *procaryotic,* monerans lack *organized nuclei* and *membrane-bound organelles.* All the other kingdoms have eucaryotic cells. Monerans are all microscopic unicellular or colonial organisms. We have yet to discover thousands of these organisms, and lack much information about how monerans operate.

The algae and protozoans compose the **kingdom Protista*** (proh TIS tuh). Since protists are both autotrophic and heterotrophic, mobile and sessile, unicellular and colonial (sometimes more than one hundred feet long), some scientists place some protists in other kingdoms.

The **kingdom Fungi** (FUN jye) is probably the newest kingdom. Although botanists have long recognized that mushrooms, molds, and other fungi are not really plants, some still try to keep these organisms in the plant kingdom, more for sentimental than biological reasons. Fungi are all heterotrophic. They may be unicellular like the yeasts or colonial like the mushrooms.

Most of the organisms we recognize as plants belong in **kingdom Plantae.** Most plants are autotrophic, but some, like mistletoe, are in part heterotrophic. Plants are usually sessile when adults. The formation of true tissues is found only in the kingdoms Plantae and Animalia. **Kingdom Animalia,** under the five-kingdom system, is not likely to be confused with plants. Animals are all heterotrophic, and most of them have some means of locomotion.

Protista: (first)

Review Questions 8A-1

1. Give two reasons for having a biological classification system.
2. Why are Artistotle's and Linnaeus's groupings of living things considered artificial classification systems?
3. List from largest to smallest the seven basic levels in the modern classification hierarchy.
4. Describe three general rules for using the modern biological classification system.
5. List the five kingdoms of living things, and give characteristics of each.

Scientific Names

A snake common in the eastern United States is pictured in figure 8A-4. Frequently called the hognosed snake because of its upturned, blunt snout, this nonpoisonous snake rarely bites. When provoked, however, it will spread its neck, open its mouth, and hiss. This imposing bluff has given it a variety of other names, including "common spreading adder," "blowing viper," "spreading viper," and "hissing snake." Still other common names for this snake include "chunkhead," "spread moccasin," and more than sixty others. But it has only one scientific name: *Heterodon platyrhinos.*

8A-4 *Call it what you will, this snake is* Heterodon platyrhinos.

Quite often a common name applies to several different organisms. The name "gopher" may refer to a salamander, a turtle, a frog, one of several snakes, or any of about fifty different types of rodents.

Tell the students that they will be told any scientific names (genus-species names) they should learn.

Since the caption is written in italics, it is a standard procedure to write the scientific name in regular type to set it off.

Answers–Review Questions 8A-1

1. (1) It is necessary for accurate communication among scientists. (2) It allows information about organisms to be studied and used in an organized manner.
2. An artificial classification system organizes organisms according to their appearance–observable characteristics. Aristotle's and Linnaeus's systems were both based on appearance.
3. Kingdom, phylum, class, order, family, genus, species
4. (1) Each group on one level of the hierarchy can be divided into several groups on the next lower level. (2) Each group has various characteristics shared by all the levels under that group. (3) Each level can be divided into various smaller units before reaching the next lower level (sub-, infra-, supra-).
5. (1) Kingdom Monera–procaryotic, microscopic, unicellular or colonial; (2) Kingdom Protista–autotrophic or heterotrophic, mobile or sessile, unicellular or colonial; (3) Kingdom Fungi–all heterotrophic, unicellular or colonial; (4) Kingdom Plantae–most autotrophic, usually sessile as adults, formation of tissues; (5) Kingdom Animalia–tissue formation, all heterotrophic, most mobile

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet correlates with the laboratory activities in this chapter. It presents identifying organisms using biological keys, differentiating between identifying and classifying, and using a biological key.

The terms **identify, classify,** and **biological key** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Even if this Facet is omitted, be sure students know the difference between *identifying* and *classifying* discussed in the first two paragraphs of the Facet.

Sometimes errors in classification are made, and another scientist must reclassify and occasionally even rename an organism. Usually, only the genus needs to be changed, and the species name is kept, but sometimes both names must be changed.

Bring several classification keys to class and identify some specimens. Carefully choose the specimens so that the classification is not too difficult for the students. Any common local animal (e.g., turtle, squirrel, or insect) can often be easily identified with a field guide.

8A-1

FACETS OF BIOLOGY

"What is it?" The Identification of Organisms Using Biological Keys

When one sees an organism that he does not recognize, he usually points a finger and asks the question biologists probably hear the most: "What is it?" To most people, being able to identify an organism by name is a worthy goal in itself. When scientists **identify** an organism they find out to which classification groups it belongs including genus, species, and sometimes even variety.

Be careful not to confuse identification with classification. To **classify** an organism a highly trained scientist assigns it to a particular group according to its characteristics. Usually the first person to find and describe the organism classifies and names it.

There are two common methods of identifying organisms. First, you can ask someone. If you can take the organism or a representative piece of it to a qualified person, he can perhaps give you its name.

Another method of identification is to use a **biological key.** A biological key presents to the user a series of questions about the specimen being identified. As the questions are answered, the field of possible organisms narrows more and more until all questions are answered and the organism is identified.

"A Simple Key to the Kingdoms" uses sets of descriptive statements, as do many biological keys. By choosing the statement that describes the organism and then going to the set of statements indicated in the margin and repeating the process, one can identify the organism.

Follow as "A Simple Key to the Kingdoms" is used to determine in which kingdom the specimen on the right belongs.

❑ **Begin with the first set of statements.** These ask about nuclear membranes and membrane-bound organelles. The picture does not reveal cellular structures. Other characteristics in the first set of statements, however, indicate that large organisms with tissues fall under the second statement. Recognizing a tree as probably being large and having tissues, you decide that the second statement best describes the organism. In the right-hand margin this choice tells

An organism to identify

A Simple Key to the Kingdoms

1. Nuclei of cells lack a membrane
   Cells have no membrane-bound organelles
   Organism is unicellular or colonial without tissues.
   Organism is microscopic .... **Monera**

   Nuclei of cells have membranes
   Cells have membrane-bound organelles
   Organism is unicellular, colonial, or having tissues
   Some are microscopic, but others are large **2**

2. Organism is unicellular or colonial **3**
   Organism has true tissues as an adult **5**

3. Organism is autotrophic and either floating or sessile .... **Protista**
   Organism is heterotrophic **4**

4. Organism is mobile .... **Protista**
   Organism lacks mobility .... **Fungi**

5. Organism is sessile (occasionally floating) and usually photosynthetic .... **Plantae**
   Organism is usually mobile and heterotrophic .... **Animalia**

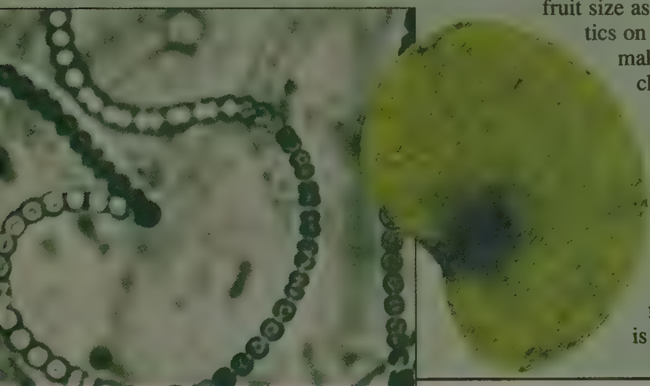
you to go to the statements in number two.

❑ **The statements in number two again ask about tissues.** The second statement is best, and in the margin you are instructed to go to the statements in number five.

❑ **The first statement in number five best describes the organism.** It also indicates in the right-hand margin that the organism being identified is in the kingdom Plantae. There are no additional numbers; you can go no farther using this key.

If you need to identify the phylum, the class, or the genus-species name of an organism, you must use additional keys. Some multi-volumed keys contain all the plants in a region of the United States. Other keys may deal only with pond algae, birds common in the East, or similar limited groups.

The ball of Nostoc *(right) would be difficult to identify. When seen under a microscope (left), it becomes easier. In what kingdom does* Nostoc *belong? Use the index to check your answer.*



Keys are important to field biologists who must identify exactly what species, and even variety, they have found. Keys also make a hike or camping trip more enjoyable. Using one of the popular *field guides* (which are actually modified keys) to identify plants and animals makes the outdoors more interesting.

Biological keys are not foolproof. If, for example, you scooped up from a pond a ball of *Nostoc* (NAHS TAHK) (see illustration below), it would be almost impossible to identify the kingdom to which this specimen belongs using "A Simple Key to the Kingdoms." By looking at it, you could not tell if it was described by the first or second statements in number one. A high-powered microscope and special stains would be necessary to note the nucleus or membrane-bound organelles. Not being able to see a distinguishing characteristic makes using a key difficult. If a key for the plant kingdom uses only flower color or fruit size as characteristics on which to make one of the choices, and the specimen being identified is not in bloom or has already dropped its fruit, the key is useless.

General keys (such as "A Simple Key to the Kingdoms") often add general statements to the primary statement to help the user if a problem arises. In "A Simple Key to the Kingdoms" the statements in the first set are of this type. Although easily misleading, they are often helpful. Some general keys make false generalizations. To avoid this, the authors of keys often find it necessary to use terms such as "usually," "often," "occasionally," and "some."

Another problem some people have with keys is not knowing what the key is describing. When a person looks at his specimen and decides that "this thingamabob must be what the key is talking about," without knowing, he stands a chance of reaching a wrong answer. One wrong choice will make all subsequent answers wrong.

Not only can the key or the user be inaccurate, but also the specimen can be atypical. If a flower normally having twelve petals is damaged so that it now has only ten, and if the key offers the choice of "twelve petals" or "fewer than twelve petals," then the damaged specimen is misleading. The key and the user of the key may be accurate, but the answer will be wrong. The use of the keys is only as accurate as the key, the user, and the specimen combined.

Review questions on page 219.

binomial: bi- (L. BI-, two) + -nom-, nomi-, or nomen- (L. NOMEN, name)

nomenclature: nomen- (name) + -clature (L. CALARE, call)

This small box should be covered by all students. The term **varieties** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Latin was chosen for the classification system for the following reasons:

- The language was not changing through usage.
- It was known by scholars.
- It is a highly descriptive language.

8A-5 *No matter what the language, this bird is* Melanerpes erythrocephalus.

The problem of which language to use to name an organism also arises. Is the bird in figure 8A-5 a redheaded woodpecker, *el pájaro carpintero con la cabeza roja, der rotköpfige Holzpicker,* or *le picoteur de bois avec la tête rouge?* If any language is chosen to name an organism, those speaking other languages will have to learn a "foreign term." If all languages are acceptable, then a scientist will have to become a linguist just to be sure he is talking about the same organism his colleagues are discussing.

Binomial nomenclature

To solve these problems, Carolus Linnaeus proposed and used a system of **binomial* nomenclature*** (bye NOH mee uhl ◊ NOH muhn KLAY chur). Binomial means "two-name," and nomenclature means "naming." Our system for naming people is binomial. "Jack Brown" tells us the person belongs to the Brown family and that he is the particular Brown called Jack.

Linnaeus needed to choose a language for his system of naming organisms. Languages that are being used by people as native tongues are constantly changing. English, for example, is changing. New words are added as new things, ideas, or actions are devised. Words also change meaning. For example, the word *charity* today means the giving of money or service. In the 1600s–when the King James Version of the Bible was translated–*charity* simply meant "love."

If Linnaeus had used his own language to name the organisms, his life's work would have become out-of-date as the meanings of the descriptive words he chose changed. Linnaeus therefore used Latin. No one spoke Latin as a "native tongue," but most scholars knew it and would thus be able to understand the scientific name of the organism. Also, because Latin is a descriptive language, it suited Linnaeus's purpose quite well.

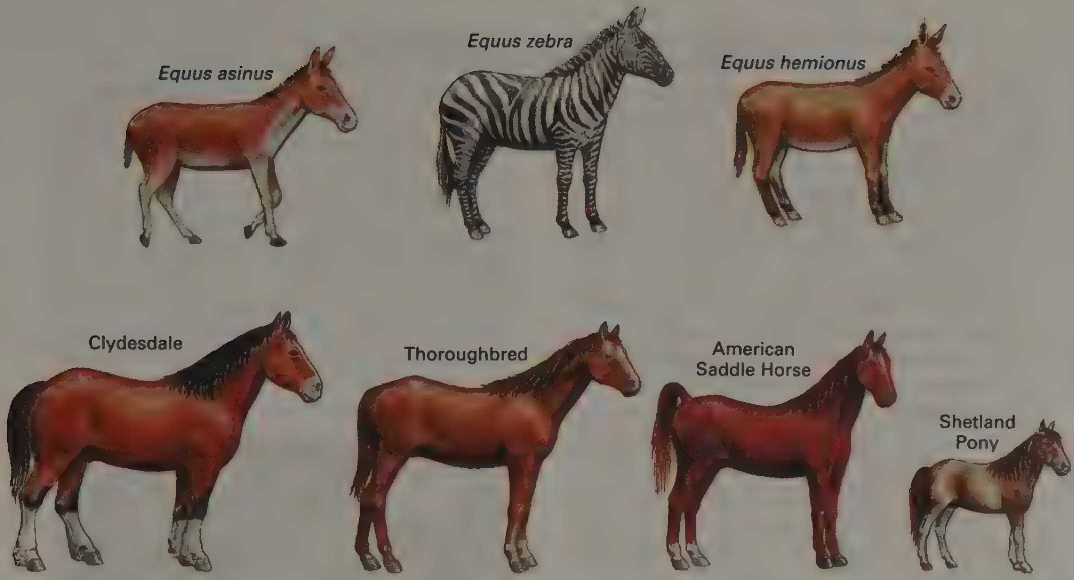
Genus-species names

The scientific name of an organism includes its genus and species names. In other words, the final two categories of the classification hierarchy for an organism are its binomial scientific name, or **genus-species name.** Since the genus-species name of an organism is a foreign term, it is printed in italics. If written or typed, genus-species names are underlined. Only the genus name is capitalized.

Varieties

A species may be a very large group of similar, but different, members. *Canis familiaris,* for example, is the genus-species name of the "familiar canine," the dog. In this particular species, however, there are many different **varieties.** Some of these varieties are purebreds, such as the collie, Irish setter, Chihuahua, Saint Bernard, and dachshund. Others may be crosses, like the pekapoo (a cross between a Pekingese and a poodle); and of course, there are many hybrids in most neighborhoods known as mutts.

As an example, let us look at the genus *Equus* (*equus* means "horse" in Latin). *Equus caballus* is the common horse. This genus and species contains horses ranging in size from the Shetland



Various species within the genus Equus *(top) and varieties within the genus-species* Equus caballus *(bottom). All are drawn to scale.*

pony to the Clydesdale. Other members of the genus are *Equus asinus*, the donkey; *Equus zebra*, the zebra; and *Equus hemionus*, which includes the onager, a wild donkeylike animal native to central Asia.

Genus can be defined as a group of similar organisms. Often the genus name and the common name are the same. For example, *Paramecium caudatum* is the genus-species name of an organism, but there is a large number of related organisms which share the common name "paramecium." However, when "paramecium" refers to the genus name, the "p"should be capitalized and the word italicized or underlined.

The species name tells which specific organism of a particular genus is being spoken of. Although the concept of a species is very useful, it is almost impossible to define, as the next section discusses.

Biological Terms

taxonomy (systematics)

The Classification Hierarchy
artificial classification system
Monera, kingdom
Protista, kingdom
Fungi, kingdom
Plantae, kingdom
Animalia, kingdom

Scientific Names
binomial nomenclature
genus-species name
varieties
genus

Facet
identify
classify
biological key

Review Questions 8A-2

1. Give two reasons for having a system of scientific names.
2. What are two reasons for using Latin to name organisms?
3. What is the primary division of a species?

Facet 8A-1: "What is it?" The Identification of Organisms Using Biological Keys, pages 216-17

1. What is the difference between classifying and identifying an organism?
2. Describe a biological key.
3. List several problems that could make using a biological key difficult or inaccurate.

Answers–Review Questions 8A-2

1. **(1)** A scientific name describes one particular organism–its genus and species; a common name may refer to several different organisms in a generalized group. **(2)** A particular organism may have several common names.
2. **(1)** Latin is unchanging, since it is not spoken today. **(2)** Because Latin is a descriptive language, it can be used effectively in describing organisms.

*3. Varieties
*From a box.

Answers–Facet 8A-1

1. Classifying involves placing an organism into a group or reorganizing organisms within groups; it requires an expert scientist. Identifying involves determining to which established group an organism belongs.
2. A biological key uses sets of contrasting characteristics to narrow the field of possible organisms until the specimen is identified.
3. **(1)** Keys make generalizations which may not be true for all organisms of a given group. Words such as *often* or *usually* must be used (inaccurate key). **(2)** People may not always understand what the key is describing (inaccurate use of the key). **(3)** The specimen may be atypical ("inaccurate" specimen).

Stressing the concept "by man for convenience" will make classification lose all its evolutionary significance.

8B-The Species and the Kind

Carolus Linnaeus thought that the number of species was established at creation. By the end of his life, he and his students had described and named almost ten thousand of them. With the possible exception of a few that might have been overlooked or not yet found in some remote places like America and the Orient, he felt that the list was complete.

Today we annually add to the lists of species about the same number of species that Linnaeus found in his entire lifetime. We estimate that there are over one million living species.

One of the reasons that Linnaeus's number of species was so small was that the world of microbiology had not yet been explored. Bacteria, of which there are over 1,500 species and an estimated 3,000 yet to be isolated and named, would probably have been grouped into a few large species by Linnaeus.

The Species

"A group of similar organisms" is probably the only definition of **species** upon which all scientists would agree. This definition, however, is not adequate. All the trees in a forest are "similar" in some ways, but they are not all one species. One problem with defining species is that the term has different meanings in different groups.

For example, a definition that applies to species of trees does not equally apply to species of fish, mammals, protists, or bacteria. Generally speaking, biologists agree that there are two major points of consideration for a definition of species.

- ❑ Members of a species are structurally similar but do have a degree of variation.
- ❑ Members of a species can interbreed and produce fertile offspring under natural conditions.

Two significant problems with this concept of species are discussed below.

Problems with the species concept: artificial characteristics

Using physical characteristics to define the limits of a species often causes problems. For example, the tiger salamander, *Ambystoma tigrinum,* lives in some ponds in the western United States. In other ponds immature salamanderlike animals called *axolotls* (AK suh LAH tuhlz) live. A particular type of axolotl was given the scientific name of *Siredon mexicana.* Later it was found that if these axolotls fed on iodine-rich material, they matured into tiger salamanders. A lack of iodine in their environment had caused them not to mature. Their appearance was so different that they were classified as a separate species when really the difference was that the pond in which they grew was deficient in iodine. Scientists no longer use the name *Siredon mexicana.*

8B-1 *The axolotl (top) was given the name* Siredon mexicana *but was later discovered to be an immature tiger salamander (bottom). Now they are both* Ambystoma tigrium. *(This axolotl is an albino.)*

Since an organism's environment can greatly affect its appearance, physical characteristics are only an artificial method of classification, prone to many errors.

Canis familiaris is the genus-species name of the common dog. It includes the toy poodle as well as the Great Dane. Along with variety,

8B–The Species and the Kind

Objectives–Chapter 8B

- ❑ Give two general characteristics of the term *species.*
- ❑ Discuss the meaning and significance of the *Biblical kind.*
- ❑ Recognize that a classification system cannot prove evolutionary theory.
- ❑ Recognize the difference between a natural and an artificial system of classification.

Notes–Chapter 8B

The genus-species concept is detailed and confusing; thus it is often omitted on the high school level. Evolutionists attempt to use it to support evolution, saying that species are changing, developing–evolving.

Although what man defines as a species may change, there is no indication that this is evolution. The concept of *Biblical kind* is relatively new. It is used by Christian scholars to help explain the problems of *species* in terms which fit both Biblical framework and observable data. It, of course, does not fit an evolutionary interpretation of the data. It is anticipated that, as evolutionists collect more data, the Biblical-kind concept will be more apparent but probably not accepted because of anti-Christian bias.

The purpose of this chapter is to put a framework for this kind of thinking in the students' minds.

though, all dogs have similarities. Dogs interbreed and produce fertile offspring. All dogs have 78 chromosomes. Dogs, then, make a species.

Canis latrans is the coyote. Although coyotes resemble dogs, they are placed in another species of the same genus because they live in particular habitats and have characteristics–coat color, size, and others–which set them apart from most dogs. But coyotes, like dogs have 78 chromosomes. Occasionally, in the wild or in a zoo, a coyote mates with a dog, and a litter of *coydogs* is born. Coydogs are fertile and have characteristics of both parents.

Although the coyote has a certain set of dog characteristics and can interbreed with dogs, it is classified as a separate species because it tends to live by itself in areas where most dogs would not live and because it rarely mates with dogs. Why is the coyote not classified as a particular variety of the dog species, like a terrier or poodle? Maybe it should be. Remember, however, that the classification of organisms was done *by man for convenience*. So far, taxonomists consider it more convenient to ignore the fact that coyotes and dogs are so similar and leave them as two separate species.

Some evolutionists wrongly use the fact that there are varieties designed into creation. By seeing what *has been called* a species mate with another species and produce offspring like both parents, some people conclude that evolution is taking place and that a new species is being formed. If two varieties of dogs were crossed, would the offspring be a new species? No. If a dog and a coyote are crossed, is a new species developing? Some would say yes, because a coydog is a cross between two species and is "new." Remember that *man* classified dogs and coyotes in different species for *convenience*. Remember also that the characteristics of the coydog came from a dog and a coyote. They may be in a new combination, but the characteristics themselves are not new.

Classification by physical appearance or location or any other outward characteristic is artificial. In these cases similarities that cannot be seen but nonetheless exist are often ignored.

Problems with the species concept: interbreeding

The sexual reproduction of a species with other members of the same species has, for quite a while, been considered a method of avoiding artificial classification of organisms on the basis of physical characteristics. If two organisms are capable of sexual reproduction and produce fertile offspring, they should be classified together, no matter what they look like. This idea seems to make sense, but let us examine it closely.

First, there are thousands of organisms (bacteria, and types of protozoans and fungi) that are not known to reproduce sexually at all. Other criteria must be used to classify these organisms.

For a second problem with interbreeding as a criterion for classification, let us look again at *Canis familiaris*. It is physically impossible for a male Saint Bernard to mate with a female Chihuahua. Even if the match were artificially made, at birth the pups would each be about the same size as their mother, which would kill either the mother or the pups long before they were born.

Should this inability to interbreed put the Chihuahuas and Saint Bernards in two separate species? If so, where should the species line be drawn? Chihuahuas can mate with dogs slightly larger than themselves, and these dogs with larger dogs, and finally, several generations and many sizes removed, a Chihuahua offspring may successfully mate with a Saint Bernard. Any line drawn has to be based on *artificial* distinctions.

Some people believe Linnaeus accomplished what he hoped to (arranging organisms by *kinds*–the Latin term *species*). Even Linnaeus, in some of his later works, admitted that his *species* was probably not the Biblical *kind*. Some people, however, take Linnaeus's stated goal and attempt to use it to support evolutionary theory.

This is similar to a Christian who finds a "proof" against evolution and bases his entire refutation on that one point. He appears to be ignoring "facts" in favor of the one proof that supports his bias. Also the Christian who says he believes the Bible but still accepts scientific facts that contradict the Bible may be trying to be "all things to all men" but actually accomplishes nothing except weakening the Bible in the eyes of other men.

Another example is *Rana pipens,* the green, spotted grass frog found in all the eastern United States and in much of Canada. The grass frog that lives in Michigan looks identical to the grass frog that lives in Florida. When these two are mated, however, all the eggs die. Research indicates that one of the unseen differences between the Michigan and the Florida grass frogs involves their rates of development. Michigan grass frogs must develop rapidly because of the shorter summer, whereas Florida grass frogs have longer summers to grow from egg to tadpole to frog.

Scientists now call Michigan frogs and Florida frogs two **ecotypes** (EE koh TYPES). Ecotypes are organisms (usually in the same species) that appear the same but are suited for one environment rather than another and often cannot interbreed.

Michigan grass frogs can mate with Ohio grass frogs, who in turn can mate with Kentucky grass frogs, and so on, all the way down to, and including, Florida grass frogs. This somewhat parallels the Saint Bernard-Chihuahua example. Saint Bernards are a variety of dog well suited for cold climates. The Chihuahua is better suited for much warmer areas. A Saint Bernard in Mexico City or a Chihuahua in a Swiss mountain village would quickly perish were it not carefully tended by man. Thus rarely would a Chihuahua and a Saint Bernard ever be together in the same geographical area. Even if they were, a Chihuahua and a Saint Bernard would not interbreed because of their sizes.

Though the Florida and Michigan grass frogs have no outward physical differences, the different characteristics are nonetheless there. It is quite probable that there are biochemical characteristics in the Michigan grass frog that, when put with the biochemical characteristics of the Florida grass frog, are lethal. These mismatched characteristics have yet to be discovered.

Evolutionists claim that ecotypes are developing species. Since "species" is a term set up *by man for convenience,* scientists may call Michigan and Florida grass frogs ecotypes or species or anything else that is convenient. Use of certain terms, however, may make it *sound* as if evolution is taking place among grass frogs. It appears that man has discovered a God-designed variation, and some scientists are attempting to use their own terminology to describe that variation in a way that helps to support biological evolution. Language, however, does not prove anything.

God's primary purpose in creating different organisms was to have them perform specific functions in specific ways in specific places, not to make them easily classifiable. Classifying organisms, however, is not wrong just because it is not easy or does not always seem to work. Organisms are classified for convenience of study.

Review Questions 8B-1

1. Give the two commonly accepted parts of the definition of a species.
2. Why are physical characteristics an inadequate basis for grouping members of a species?
3. List two reasons that interbreeding is a difficult basis to use for grouping organisms into species categories.
4. What is an ecotype? What is the difference between an ecotype and a variety?

The Biblical Kind

Scripture does not include a detailed classification system. Occasionally it includes lists of organisms. What God created on which day of the creation week and which organisms were brought into Noah's ark have been suggested as classification systems. These are simply lists, though, and are not meant to be classifications.

The Scriptures state that God created each organism to reproduce "after its kind" (Gen. 1:9-25). It appears that God has established the **Biblical kind** as the natural grouping of organisms and that the ability to reproduce is the criterion established for classification into a Biblical kind.

Carolus Linnaeus, a creationist, thought that he was distinguishing the *kinds* referred to in Gene-

Answers–Review Questions 8B-1

1. **(1)** Members of a species are structurally similar but do have a degree of variation. **(2)** Members of a species can interbreed and produce fertile offspring.
2. Environment can greatly affect the physical appearance of many species.
3. **(1)** Many organisms reproduce by means other than sexual reproduction. **(2)** After many generations of breeding, the offspring of one variety may be able to interbreed with another variety that it normally would not have been able to breed with (e.g., Chihuahua and Saint Bernard).
4. Ecotypes are organisms (usually in the same species) that appear the same but are suited for one environment rather than another and often cannot interbreed. A variety is a subgrouping of a particular species; varieties can exist in the same habitats and usually interbreed freely to produce fertile offspring.

sis as he identified his species. Linnaeus was the first to use the term *species,* which means "kind" in Latin, as a classification unit. But Linnaeus, like modern taxonomists, used various physical characteristics to determine his classifications and therefore had an *artificial* system.

The dog kind

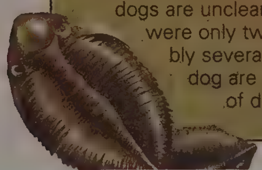
Let us once again consider the species *Canis familiaris.* Linnaeus recognized the possibility of variation and did not put all the varieties of dogs into separate species. The coyote, however, is a separate species according to Linnaeus since it does not naturally interbreed with dogs. Examination, however, shows that the coyote is probably part of the same kind as the dog since dogs and coyotes are capable of interbreeding.

Are there other organisms that should also be placed in the dog kind? What about wolves? It is possible. In order to make a good judgment about which organisms should be placed into the dog kind, extensive breeding experiments would have to be conducted. The failing of a few matings should not significantly affect the conclusions.

Noah's Flood and the Biblical Kind

Many animals and plants which were alive before the Flood are extinct today, it seems. God apparently created a greater variety of organisms than now remains. However, every extinct organism is similar to existing organisms. Dinosaurs were very similar to reptiles that have survived. Trilobites (TRY luh BITES), common fossil forms, are easily classified because they are very similar to organisms alive today. It is possible but not probable that although different groups within a Biblical kind may have become extinct, either naturally or by man's efforts, there are still the same number of kinds existing on the earth.

In any case, the number of animals on the ark could have been far fewer than two of all the land-dwelling and seven of all the clean *species.* God brought *kinds* on the ark. For example, since dogs are unclean, we can assume that there were only two of them on the ark. Possibly several other species similar to the dog are the offspring of the one pair of dogs on the ark.



Trilobites

Remember that Chihuahuas and Saint Bernards do not directly interbreed, but they can "indirectly." The expense, time, and lack of know-how necessary to perform extensive breeding experiments make it probable that we will never know how far the dog kind extends.

Some people claim that Linnaeus unknowingly hurt the cause of creationism. By setting up his species and equating them with Biblical kinds, he implied that his species could not interbreed and that new species would not develop. But species do interbreed (a fact which Linnaeus recognized), and a new set of characteristics can occasionally occur in the offspring of the interbreeding of two species. The hybrid organism may be so different that, according to the currently accepted definition of species, a new species has developed. This type of development has been used to demonstrate biological evolution. The expressing of old genes in new combinations within a Biblical kind, however, is not evolution.

A natural classification system

Today scientists are looking for a more **natural system of classification,** a system based on genetic similarities, not on physical characteristics. Genetic similarities, according to evolutionists, prove common ancestry. In other words, evolutionists are trying to classify organisms according to evolutionary relationships. The experimentation necessary to determine genetic similarities is very costly and time consuming, but occasionally scientists discover a fact that they think helps in establishing the natural classification system. When this new system is all worked out, they expect to have an accurate phylogenetic tree, proving evolution.

At this point we enter speculation, but speculation with Scriptural backing: it would be interesting if scientists distinguished groups of organisms whose members are capable, although possibly indirectly, of interbreeding within the group but not with members of other groups. When this happens, we will *not* have arrived at what the evolutionist was looking for–the path evolution has taken–but we will be closer to realizing what God created–the Biblical kind.

The evolutionist seeks to find a natural system of classification, one which is based upon genetic similarities. He *assumes* that when he is able to deal with genetic characteristics as easily as he counts legs and teeth, he will find what has eluded him on his phylogenetic trees–the pathway evolution took. (Forget the missing links and most common ancestors.)

However, it is far more logical to assume that the natural system of classification based on genetic similarities will show *groups* of genetically similar organisms (the Biblical kinds) which are each distinct, not interbreeding. In other words, even some of the species which now appear to be in different groups (e.g., fox and dog) may be as similar as the toy poodle and Great Dane–just distant puddles of the same gene pool–or both in the same Biblical kind.

See the study of the dog gene pool (pp. 157-58).

Migration and adaptation are crucial aspects of evolutionary theory. Migration does happen, but it would require a great deal of *survival of the fittest* (see pp. 196-97) for it to play any significant role in speciation. Adaptation, of which there is no adequate example that ever passes beyond what could be called variation, resembles Lamarck's theories of need, use and disuse, and inheritance of acquired characteristics.

Migration, Adaptation, and the Evolution of Species

It seems logical to assume that following the deluge as the animals moved away from Noah's ark, they formed into loose groups and in time they became distinct groups by natural selection. **Migration,** the moving of organisms from one area to another, can cause a separation of traits to the extent that the groups of organisms could be called two different species. For example, as dogs migrated into semiarid areas, those having long legs, trim bodies, and short hair may have been favored, and the short-legged, heavy-bodied, or long-haired dogs were probably selected against. It appears that in time a population of dogs homozygous for these many traits–the coyotes–developed.

Evolutionists say that this migration and selection is evolution since, according to their definition, a new species has developed. To the contrary, this rearrangement and selection of characteristics is not evolution. A new, more complex organism has not evolved. Rather than new genes being formed, certain genes appear to be eliminated from a small population within a Biblical kind. Such a change is not biological evolution.

To the concept of migration, evolutionists often add adaptation. **Adaptation** is what an organism does when it finds itself in a different environment, either one to which it is not completely suited or one to which it is not accustomed. You would adapt to a cold climate by wearing more clothes or changing your activities.

Assume that dogs migrating into a new area did not find their usual food. These dogs could either continue to migrate, die off, or adapt by eating something else. Suppose mountains or oceans prohibited migration. If there were abundant bird eggs, the dogs might learn to eat them. In other seasons the dogs could possibly adapt by eating insects. Natural selection might favor those dogs that could eat bird eggs and insects most easily. Evolutionists would quickly claim that a new insect-eating dog species had developed and that evolution had taken place.

Such an adaptation to eating eggs and insects, however, did not make any new dog characteristic. Most dogs refuse to eat insects. But if a dog has been forced to eat insects and even prefers them because it has eaten them all its life, evolution has not taken place. An organism can only adapt as far as the organism's genetic makeup will permit. In other words, there are limitations to adaptation. A dog's digestive system, for example, will not permit it to adapt to a diet of grass. An adaptation beyond the natural variations possible in an organism would require mutations. Mutations, however, are random and not based on need.

The eight people on the ark are the ancestors of all people alive today. Yet today everyone does not have the same characteristics nor the same lifestyles. The various races and cultures of people probably developed through migration and adaptations within the limits of variations.

Biological Terms

The Species	*The Biblical Kind*	
species	Biblical kind	migration
ecotype	natural system of classification	adaptation

Review Questions 8B-2

1. What is the primary characteristic which would place an organism into a Biblical kind?
2. List several possible problems with recognizing the Biblical kinds in today's world.
3. How do evolutionists explain biological evolution by migration, selection, and adaptation?
4. Explain how migration, selection, and adaptation might account for various groups of animals coming into existence after the Flood.
5. Why are migrations, selections, and adaptations that establish new groups of organisms not evolution?

Thought Questions

1. Suppose a Christian objects to the modern system of classification, saying that since he does not see a basis for it in Scripture, it is wrong. Prepare an answer for this person.
2. Compare a natural and an artificial system of classification of living things.

Answers–Review Questions 8B-2

1. The ability to reproduce is the criterion used to establish a Biblical kind.
2. **(1)** Migration of organisms causing separation of traits; **(2)** adaptation to various environments; **(3)** natural selection for various traits (selection of existing characteristics)

*3. They state that migration and selection bring about a new species. They combine this with adaptation to claim the development of a new species.

*4. Migration, selection, and adaptation could have led to the separation of various groups into new habitats. Through selection, those organisms with a particular characteristic necessary for survival in a certain environment would have continued to reproduce this variety. Adaptation would have changed some of the habits of certain species. All these changes could have brought about rearrangement and selection of genes and traits, but they would not have produced new genes in new species.

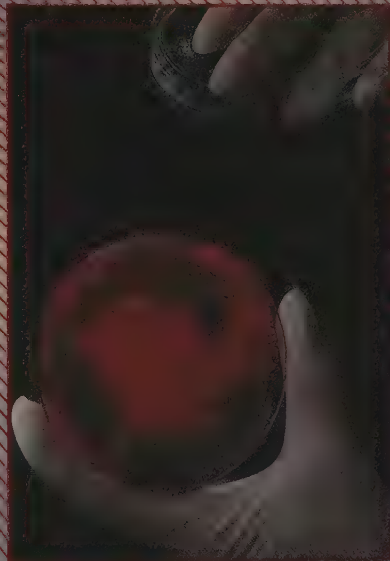
*5. These occurrences do not produce or develop new genes or new species; they account only for rearrangement and selection of already existing ones.

*From a box.

Answers–Thought Questions

1. The only problem with objecting to the modern system of classification is that all other proposed systems are impractical and more difficult. For example, some creationists propose the formulation of a classification system according to the days of creation. You need only try to do this to understand how illogical it really is.
2. Natural classification systems are based on genetic similarities. Artificial classification is based on external characteristics.

THE KINGDOM MONERA AND THE VIRUSES
MICROBIOLOGY PART I



NINE

Time Frame
9A (with Facets): 2-3 periods
9B (with Facet): 1-2 periods
9C (with Facet): 1-3 periods

Laboratory Activities
9A–*Bacterial Basics* is designed to be a demonstration showing students the basic techniques of culturing bacteria and permitting students to observe bacteria. It can be done in $\frac{1}{2}$ a period, with follow-up observations (taking only a few minutes) the next 2-3 periods.
9B–*Bacteria and Antibiotics* is a second demonstration. It takes only a few minutes, with follow-up observations (taking only a few minutes) the next 1-3 periods.

9A–Bacteria and Similar Organisms

Monera, is in some respects, the largest kingdom. It contains the tiniest known cells; many monerans are visible only with the aid of the higher powers of a light microscope. It is estimated, however, that monerans have a greater combined weight than all the other living things on the earth.

Moneran cells are, on the average, 1,000 times smaller than most human cells. They may be small, but they are numerous. The monerans that live on your skin and in your digestive tract outnumber the cells of your body.

Monerans thrive in places where no other living thing is known to exist. In the atmosphere 6,096 m (20,000 ft.) up, they ride on dust particles. In hot springs at 98° C (208° F) and in melted glacial water, representatives of the kingdom Monera multiply. One gram of common soil contains from 1 to 100 million of them. They exist in every natural water supply, including the water that you drink. Every cubic meter of air contains from 100 to 20,000 of them. Despite the fact that monerans are almost everywhere in astonishing numbers,

A single drop of water can contain 50 billion bacteria.

9–Microbiology Part I: The Kingdom Monera and the Viruses

In scientific circles, the organisms in the kingdom Monera and the viruses (not considered living, hence not classified) are thought to be significant. Bacteria are the major organisms of decomposition. Viruses are among the major causes of diseases, not only in humans but also in every other organism which has been studied carefully enough to notice diseases. Many viral diseases appear to be under control; many are not. In the future, because of mutations, some which now appear under control may not be.

Students are generally not interested in the study of bacterial structure and culture. Agar, nutrient broth, and little slimy-looking lumps the teacher calls ''real bacteria'' may arouse a passing interest but do little to actually motivate learning for most of today's high school students.

To overcome this microbiological apathy, the teacher will need to stress constantly the role that these organisms play in everyday life. In each section of this chapter, there are abundant references to the practical applications of the groups being discussed. The teacher must not become so involved in the teaching of the structures and cycles that he fails to teach the relationship of the material to the diseases, the uses, the problems, the threats, the values, and the present and future methods of dealing with the organisms and structures being discussed.

The last section of this chapter (9C–*Diseases and Disorders*) has more of an innate interest factor than the rest of the chapter. Students, however, often find it more difficult because it is more abstract. Care must be taken to make sure the principles relate to what students need (and want) to know.

bacteria: (Gk. BAKTRON, rod)

pathogenic: patho- (Gk. PATHOS, emotion or suffering) + -genic (birth)

coccus: (Gk. KOKHOS, berry or pit)

bacillus: (L. BACILLUS, rod)

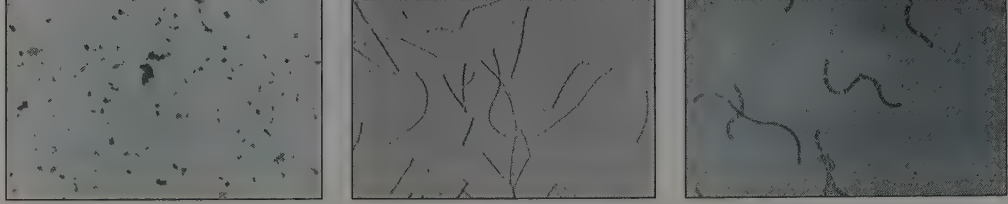
spirillum: (L. SPIRILLUM, a coil or a twist)

Answers–Caption 9A-1
Left, diplococcus; center, streptobacillus; right, spirillium

The old phyla terms *Schizomycophyta* and *Cyanophyta* are rapidly being replaced by several new phyla terms. These have been presented in Appendix B and will not be discussed in the chapter. For the purposes of this text, all bacteria will be grouped together as *Monerans*. Rickettsias, mycoplasmas, spirochetes, and blue-green algae (cyanobacteria) are discussed as groups within the kingdom Monera, but specific classificational names are avoided.

Emphasize the paragraph that deals with bacteria serving as the primary decomposers of organisms.

A staph infection results from *staphylococcus* bacteria. Strep throat is an infection of *streptococcus* bacteria.



9A-1 *Three different bacteria. Determine the shape and type of each.*

scientists have only recently devised techniques for studying them and have a great deal yet to learn about them.

At one time scientists placed the members of the kingdom Monera in the plant kingdom. Various cellular characteristics, as well as the fact that some of these organisms make their own food by photosynthesis, made this seem logical. However, most biologists are now convinced that monerans should be in a kingdom by themselves. The key characteristic which places organisms in this kingdom is that they are all *procaryotic;* that is, they all lack organized nuclei and membrane-bound organelles. (See Appendix B for a summary of moneran characteristics.)

The Bacteria

When bacteria and similar organisms were first observed it was simple to place them all in one large group. Artificial characteristics were used to place them into subgroups. Today a **microbiologist** (one who studies microbes) uses various techniques to classify monerans. With the exception of a few groups we will lump all the monerans together and call them bacteria.

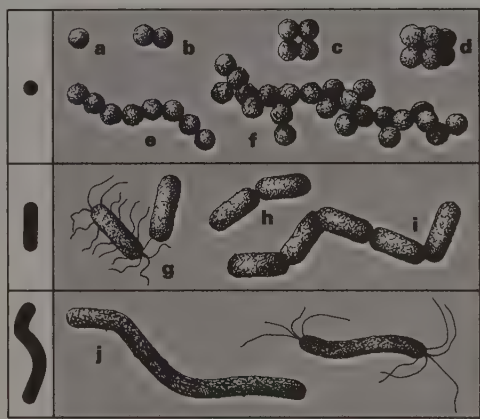
When most people think of **bacteria*** (sing., bacterium), they think of germs which cause diseases. Many bacteria are *pathogenic* (disease causing), but most are not. Most bacteria are vitally important to living things, including humans, because of their effects on dead things.

Bacteria (along with fungi) are the primary **decomposer organisms** in soil and water. Decomposer organisms produce enzymes that break down proteins, starches, lipids, and almost every other known organic substance. Without this action by bacteria and fungi, in a few generations all the materials necessary for life would be contained in nondecomposing dead bodies. Think of what our world would be like if dead things were not decomposed, and you will realize that bacteria and fungi are essential to all life.

Bacterial Shapes, Sizes, and Colonies

Generally speaking, bacteria are one of three general shapes.

- *Coccus* A spherical bacterium, averaging about 1 µm in diameter, is called a **coccus*** (KAHK us)(pl. cocci). A period (.) could easily have 5,000 cocci bacteria lined up across it.
- *Bacillus* A rod-shaped bacterium is called a **bacillus*** (buh SILL us) and averages 1 µm in width and 2-10 µm in length.
- *Spirillum* A **spirillum*** (spy RILL um) is a spiral-shaped bacterium that is slightly longer than the bacillus type.



9A-2 *Bacterial shapes and colonies.* **Top,** *coccus* **(a)** *coccus;* **(b)** *diplococcus;* **(c)** *tetrad;* **(d)** *sarcina;* **(e)** *streptococcus; and* **(f)** *staphylococcus.* **Middle,** *bacillus:* **(g)** *bacillus;* **(h)** *diplobacillus; and* **(i)** *streptobacillus.* **Bottom,** *spirillum:* **(j)** *spirillum.*

9A–Bacteria and Similar Organisms

Notes–Chapter 9A

Bacteria are among the most significant organisms on the earth. Most people, however, would not recognize a picture of them and could not tell how to go about finding them, where they live, or even what bacteria do. The primary thrust of this chapter is to inspire the students to appreciate and understand the role of bacteria in natural conditions and in some of the new technology-related areas.

The classifications within the kingdom Monera that scientists use today require a depth of understanding of bacteria and similar organisms beyond the scope of this text. Thus, this text omits the names of the phyla (properly called *divisions* but for uniformity called phyla) and other groups. Without scientific delineation, the monerans will be dealt with as a major group, containing a few subgroupings. Thus the blue-green algae, which were in phylum Cyanophyta, are now the cyanobacteria and are in one of the bacterial phyla. Several bacterial phyla are listed and briefly described in Appendix B, a good beginning point for a more detailed unit on bacteria.

Only teachers should handle cultures of bacteria in a high school classroom because of the threat of introducing pathogens. Also, the time spent teaching the proper laboratory techniques to safely handle bacteria is not well invested in a general survey class, since most students will use these techniques only once. Demonstrations with bacteria in which the students observe the results are relatively easy and highly recommended.

The boxes about cyanobacteria and about rickettsia, spirochetes, and mycoplasmas can both be covered quickly. These are included to provide a well-rounded study of viruses and bacteria. Each of these groups contains organisms which relate to humans in significant ways, but the boxes

9A-1

FACETS OF BIOLOGY

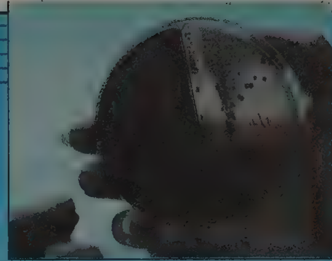
Uses of Bacteria—Past, Present, and Future

Because bacteria produce only certain chemicals as they break down their nutrients, various bacteria are useful in industry. Bacteria are used when making cheese, yogurt, silage, sauerkraut, and buttermilk. Natural products of bacterial fermentation, such as alcohol, vinegar (acetic acid), and lactic acid, are also useful since they are often the cheapest source for these substances. Other bacteria are useful sources of vitamins (B_{12}, C), amino acids, and most antibiotics.

In the past, most of our uses for bacteria have involved the ability of bacteria to rapidly decompose substances. Today, however, scientists are changing bacteria. Through genetic engineering, bacteria can be made to produce substances that are useless to them, but are useful to humans. Often these bacteria are cultured and then destroyed to obtain the desired substances they produced.

Bacteria are now being used as sources for insulin, human growth hormones, interferons, blood proteins, and other substances. Most of these are produced by human genes that have been placed in bacteria. In the past many of these substances were unavailable except from human sources (donated blood or cadavers). Now a cheap, reliable source for "human" substances is available using genetically engineered bacteria.

Scientists hope to design bacteria that will do profitable things in the environment, not just in the laboratory. Some bacteria, for example, grow on plant leaves and protect them from frost. But these bacteria only grow naturally on certain plants. Scientists are working on ways to get the frost-resistant properties of those bacteria into other bacteria that grow on crop plants. Releasing such genetically engineered organisms in the environment does present some concerns: What will be the effect of this organism on other plants, animals, humans? What will it do when it gets into a stream or lake? Costly and time-consuming research is necessary before anyone can make a wise decision regarding release of genetically engineered organisms into the environment.



By culturing bacteria on different media, scientists can identify many species.

Review questions on page 229.

This Facet contains examples of much of the content of the chapter and should be read by the students, but it need not be covered in class.

There are no new concepts presented or terms in this Facet which are listed in the Biological Terms section at the end of the chapter. The material is designed to be informative. Many teachers find here the material they need to illustrate the points in lectures about bacteria and do not cover the Facet itself in lecture.

Information about releasing materials into the environment and its possible consequences are discussed on pages 163-64.

Commercial Uses of Bacteria

Forming cheeses and similar products A starter bacterium added to milk forms lactic acid and causes *curdling* (the separation of milk solids and fluids). The resulting lumps are the *curds* which contain milk proteins, fats, and minerals. The watery substance is *whey.* If most of the whey is drained, the resulting moist curds are *cottage cheese* (and similar types). *Cream cheese* is produced by adding butterfat to curds. Most other cheeses are the result of time, temperature, and the kind of bacteria (or mold) growing in the curd.

Making vinegar Yeasts ferment the sugars in fruit juices into alcohol in an airtight container. Bacteria *(Acetobacter)* then oxidizes the alcohol into acetic acid (vinegar).

Retting flax When the stems of the flax plant are placed in warm water, the soluble materials from the stems form a medium for a bacterium. The pectin which holds the plant fibers together is fermented by enzymes produced by this bacterium. After about two weeks the stems can be removed and the fibers separated. The fibers can then be processed into linen. This process, used during Bible times, is still used today.

Making sauerkraut In an oxygen-free container a bacterium *(Lactobacillus)* ferments the sugar in shredded cabbage into lactic acid (along with small amounts of alcohol), making sauerkraut.

Tanning leather Certain bacteria are used to remove hair from and to make hides pliable.

Forming silage Silage is a rich food for cattle made of chopped corn stalks, alfalfa, clover, and other plant substances. The plant material is placed in an airtight silo. Soon all the available oxygen is used by plant cells, and an anaerobic bacterium *(Lactobacillus)* then converts the plant sugars into lactic acid, resulting in silage.

Bacteria are used in making cultured buttermilk. Skim milk can be inoculated with bacteria which break down some milk substances to lactic acid. As other materials in the milk decompose, desirable aromas and tastes are formed, resulting in cultured buttermilk.

Objectives—Chapter 9A

- ❑ Describe the cellular structure of bacteria.
- ❑ List and describe the basic cellular shapes and colonial forms of bacteria.
- ❑ Describe and explain the significance of bacteria as decomposer organisms.
- ❑ Describe bacterial reproduction and discuss the limitations of bacterial reproduction.
- ❑ List various methods bacteria use to obtain energy.
- ❑ List and describe the various types of bacteria in relation to their oxygen requirements.
- ❑ List the basic requirements for bacterial growth.
- *❑ List several commercial uses of bacteria.
- *❑ Describe several methods of controlling bacterial growth.
- ❑ Compare the mycoplasmas, rickettsias, and spirochetes to more typical bacteria and tell the significance of these groups.
- ❑ List and explain the significance of the major characteristics of the cyanobacteria (blue-green algae).

*From a Facet.

Visual 9A-1 can be used to teach bacterial structure, shapes, and colonies.

Some bacteria are *pleomorphic;* that is, they can have more than one shape, depending on growing conditions or age. Identification must then be based on the appearance of young, actively growing cells.

Review material about procaryotic cells (pp. 72-73) and about cell walls and capsules (p. 75).

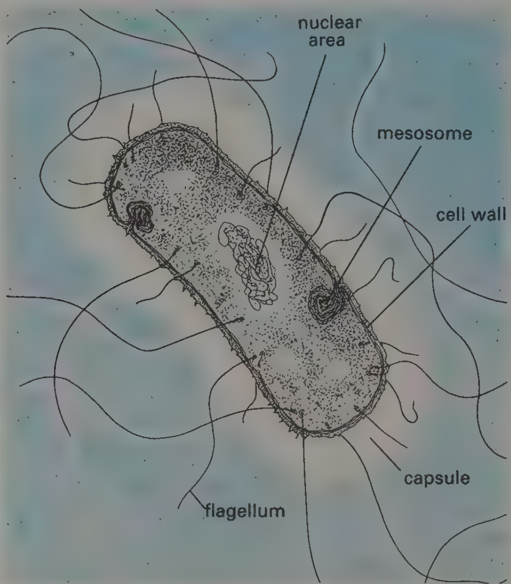
Streptococcus pneumoniae was previously called *Diplococcus pneumoniae* (also see p. 232).

In paper mills, encapsulated bacteria stick to the rollers, causing uneven spreading of pulp.

Scientific names of bacteria often describe a characteristic of the cells. "Coccus," "bacillus," and "spirillum" are often found in genus-species names. Bacterial cells also form colonies, which are sometimes used in identifying and naming bacteria. Large bacteria can be seen when magnified about 400X. Most bacteria, however, are so tiny that they must be magnified 1,000X.

Structure of a bacterial cell

Bacteria are procaryotic (lacking a true nucleus). The DNA in a bacterium forms a single, circular chromosome. If this circular DNA were stretched out, it would be about 1,000 times as long as the cell itself. Normally this chromosome appears in a non-membrane-bound **nuclear area.**



9A-3 *Structure of a typical bacterium*

Although bacteria do not contain membrane-bound organelles, they do contain cellular membranes. **Mesosomes** appear to be twisted indentations of the cell membrane. Mesosomes in different bacterial cells have various enzymes attached to them. Photosynthetic bacteria, for example, usually have some of the enzymes used in bacterial photosynthesis attached to mesosome membranes. Membrane-bound enzymes of cellular respiration are often in the mesosomes.

Ribosomes, the non-membrane-bound organelles associated with protein formation, are abundant in bacterial cytoplasm. Some bacteria contain globules of fats, starches, and proteins.

Bacterial cell walls and capsules

Immediately outside the cell membrane most bacteria have a *cell wall.* Bacterial cell walls lack cellulose and contain several chemicals found only in bacterial cell walls. Bacterial cell walls are rigid, giving each cell its particular shape.

Outside the cell wall bacteria have a **capsule** made of gummy, complex carbohydrates of different types, depending on the bacterial cell. Some capsules are very thin; others may be several times the thickness of the cell. The capsule protects the cell from drying out during temporary dry periods and prevents certain substances from entering the cell. Any substance entering the cell must first pass through the slimy capsule.

The thickness of the bacteria's capsule appears to affect an organism's ability to combat infection by that bacteria. *Streptococcus pneumoniae,* for example, is a bacterium which comes in several strains, some with a thick capsule and some with almost no capsule. When the non-encapsulated strains are injected into laboratory mice, few if any symptoms develop. When an encapsulated strain is injected, the mice develop pneumonia and die. The mouse's body can destroy the non-encapsulated variety but has little effect on the bacteria which have a thick capsule.

Bacterial movement

Many spirilla, bacilli, and a few cocci have *flagella.* A bacterial flagellum is a long threadlike structure usually less than 0.05 μm in diameter but often several times the length of the cell. Bacterial flagella lack the microtubule arrangement of the flagella in eucaryotic cells. Spirilla with flagella usually have clusters of flagella on each end, but bacilli often have flagella scattered over the cell. Most bacteria with flagella are able to direct their movements: they usually proceed either toward or away from some stimulus. Photo-

may be easily skimmed or even omitted if necessary.

Facet–Chapter 9A

To help teach the content of the chapter, be sure to use the material in both Facets, *Uses of Bacteria* and *Controlling Bacteria.* Even if students are not required to learn the material in the charts, use the information as illustrative material to teach the chapter. For example, when speaking of the rapid reproduction rate of bacteria, indicate that refrigeration is one method man uses to stop bacteria in food from growing to large numbers. When speaking of endospores, discuss the need to destroy them when canning food. When speaking of anaerobic bacteria, discuss vinegar, sauerkraut, and silage. This will be a much better use of the Facet content than to merely go over the Facet, repeating its content.

synthetic bacteria, for example, swim toward the light source.

Bacterial cells which lack flagella appear to vibrate back and forth as water molecules bump into them. Even bacteria with no known form of movement seem to be able to go toward or away from certain stimuli. All bacteria are small enough to be easily carried along with even the slightest fluid current. It does not take much outside influence to move these small organisms.

Review Questions 9A-1

1. List several characteristics of the kingdom Monera.
2. What is the primary function of bacteria in nature?
3. What are the common cellular shapes and colonies of bacteria?
4. Describe the cellular structures of bacteria.
5. What are two common methods of bacterial movement?

Facet 9AF-1: Uses of Bacteria–Past, Present, and Future, page 227

1. What natural properties of bacteria have been used by man in the past?
2. List several ways man has used bacteria in industry.
3. What process now makes bacteria more useful to man?

Bacterial Growth and Reproduction

Under ideal conditions many bacteria are able to grow to full size and divide every 30 min. If these conditions persisted, in about 30 generations (15 hr.) a single bacterial cell would be multiplied to over 1 billion cells. An hour later the initial cell would have become about 4 billion cells. In less than 24 hr. the mass of bacterial cells would weigh over 2,000 tons. In another day there would be billions of tons of bacteria. Within a week the bacteria would weigh more than the earth.

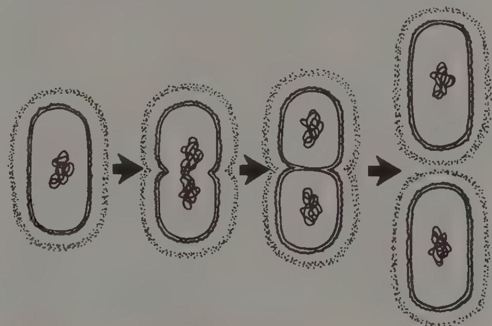
The "clump of bacteria that smothered Chicago," however, is science fiction. Even laboratory cultures of bacteria cannot sustain such a growth rate for long. The bacteria on the outside of a clump may maintain a high metabolism, but those in the center of the mass do not get enough of the materials necessary for growth. Soon the central cells are in a pool of wastes and dead cells. The ideal range of conditions for high metabolism in bacteria is often quite narrow and difficult to maintain for a large quantity of bacteria over an extended period of time.

Reproduction in bacteria

Normally bacteria reproduce by simple cell division. This asexual reproduction does not involve mitosis. After the replication of the bacterial chromosome and the separation of the two daughter chromosomes, an invagination of the plasma membrane forms daughter cells.

Some bacteria can complete cell division in 9 min. Following about 10 min. of growth under ideal conditions, these cells will be full size and ready to divide again. Most bacteria grown in a laboratory can divide about every 30 min., but certain bacteria require 3-4 hr. Some pathogenic bacteria divide only once or twice a day.

During mildly unfavorable conditions, many bacteria decrease activities and wait the return of favorable conditions. This reduced metabolism preserves certain soil bacteria during the higher temperatures of a summer afternoon and the cooler evening temperatures of the spring or fall.



9A-4 *Asexual reproduction of bacteria*

Culture or obtain from a hospital several Petri dishes of bacteria for the class to observe, and then discuss steps taken to control bacteria.

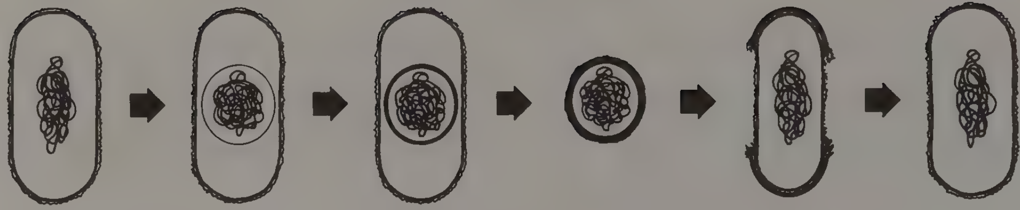
Answers–Review Questions 9A-1

1. They have microscopic cells and are procaryotic (see Appendix B).
2. Decomposition
3. Coccus (round), bacillus (rod shaped), and spirillum (spiral shaped) are the most common shapes. Colonies are illustrated in diagram 9A-2 (p. 226).
4. They have a cell wall that lacks cellulose, a capsule composed of carbohydrates outside the cell wall, and a cell membrane. They lack a true nucleus but have a nuclear area with spiral DNA that forms a single circular chromosome. They also have ribosomes and mesosomes with enzymes attached. Many bacteria move by means of flagella.
5. (1) Flagella; (2) vibrations as water molecules bump into them (Brownian movement)

Answers-Facet 9A-1

1. Bacteria decompose specific substances, thus making other substances.
2. See box on p. 227. Bacteria are also a source for some vitamins and antibiotics.
3. Genetic engineering can now introduce new characteristics to bacteria. Gene splicing (recombinant DNA) is used to accomplish this. Bacteria are now a source for insulin, human growth hormones, blood proteins, and other protein products.

endospores: endo- (within) + -spores (seed)



9A-5 *The formation and germination of bacterial endospores*

Visual 9A-2 can be used as an outline for presenting material regarding bacterial nutrition. Note that the kinds of nutrition are presented roughly in order according to the number of known species. In other words, there are more saprophitic than parasitic bacteria; there are more parasitic bacteria than cyanobacteria, etc. Examples of parasitic bacteria include the mycoplasmas, rickettsias, and spirochetes.

Some students confuse pasteurization and homogenization. When milk is homogenized, it is processed so that the cream does not separate and rise to the top; the milk does not need to be shaken. Have students take the word *homogenized* apart to see its meaning.

Students should remember Pasteur from his swan-necked flask experiment (p. 22).

Simple experiments can show how various bacteria need specific conditions. Adjusting pH or temperature is probably easiest. Cultures of photosynthetic bacteria, some grown in light and others in darkness, make an excellent experiment, the results of which can be seen in 24-48 hours.

Some bacillus bacteria and a few other types are capable of forming **endospores*** to survive extended periods of unfavorable conditions. These bacterial endospores differ from the spores of most other organisms in that they are formed within the plasma membrane. Several layers of hard materials form around the nuclear area as an endospore is formed. Within the endospore metabolism is reduced to a low level.

Some endospores can withstand 20 hr. of boiling. Others can withstand freezing, dryness, extreme pressure, and even poisonous gases. When favorable conditions return, the endospore coats (which may be in layers) weaken, bacterial growth resumes, and the cell bursts out of the endospore case. Although the formation of endospores is not a method of reproduction, it is a method of continuing the species of bacteria.

Bacterial nutrition

Of all known groups of living things, bacteria have the widest range of methods for obtaining usable energy and building organic substances. The most complex biosynthesis in bacteria takes place among the *autotrophs,* both the *photosynthetic* and **chemosynthetic** varieties. Some of these bacteria are almost completely independent, requiring only inorganic materials in order to live.

Some bacteria carry on photosynthesis that is considerably different from the photosynthesis carried on by other organisms. *Bacteriochlorophyll* is usually purple, red, or brown. These colors permit bacterial photosynthesis to be carried on in places like the depths of a pond, where the wavelengths of light necessary for green chlorophyll to function could not penetrate. Whereas the photosynthesis carried on by green chlorophyll uses water as a hydrogen source, bacterial photosynthesis usually obtains hydrogen from hydrogen sulfide or other substances. Oxygen, therefore, is usually not a product of photosynthesis involving bacteriochlorophyll.

Although not a large group, the chemosynthetic bacteria perform some important conversions of inorganic materials. Chemosynthesis involves converting inorganic compounds other living things cannot use into usable forms and capturing the escaping energy. Chemosynthetic bacteria use this energy to form materials (usually carbohydrates) for their own use.

The vast majority of known bacteria are *heterotrophic,* obtaining their energy by digesting organic substances. The bacteria we usually think

Pasteurization

The preservation of milk presents a special case. If raw milk is heated enough to destroy all bacteria, it loses some of its flavor and food value. Louis Pasteur first devised the process of pasteurization to prevent the souring of wines. It was later used on milk to eliminate the bacteria that caused tuberculosis. Pasteurization is now widely used to control pathogenic and spoilage bacteria in dairy products and fruit juices.

Commercial **pasteurization** of milk involves raising the temperature to either 63° C (145° F) for 30 min. (the holding method) or to 72° C (161° F) for 15 sec. (the flash method) and then quickly cooling the milk. Pasteurization destroys between 90-99% of all bacteria. Pasteurized milk, although it sours much more slowly than raw milk, should still be refrigerated to slow bacterial activity. Sterilized milk, which does not require refrigeration, is now available.

Exposure to the air permits new bacteria to enter processed dairy products, and for this reason processed milk should be kept covered.

Facets of Biology

9A–2

Controlling Bacteria

Although in some ways man relies heavily on bacterial metabolism and even encourages bacterial growth in some instances, many of man's dealings with bacteria are attempts to control them. Medical science has invested much time and money in attempts to control pathogenic (disease causing) bacteria (see Chapter 9C).

Since bacteria decompose organic material, we should not be surprised that bacteria are among our primary competitors for food. Many foods would remain edible for months were it not for bacterial action fermenting carbohydrates, putrifying proteins, and turning fats rancid. We have two basic ways of controlling bacteria in our food:

- Destroy the bacteria present and seal the food in a container which will not permit the entrance of other bacteria and
- Place the foods in an environment that will not permit bacteria to grow or at least not grow rapidly. The bacteria may be present, possibly in a dormant form, but they either will not spoil the food or will spoil it less rapidly.

Some of the more common methods of food preservation are as follows:

- **Canning** In canning, the food is heated enough to destroy all pathogenic and most other forms of bacteria and then sealed in a can or jar to prevent growth of the residual organisms and the entrance of new ones. Canned foods can keep for extended periods but many foods lose desirable qualities in the process. Canning is primarily used for fruits, vegetables, meats, and prepared foods.
- **Preserves or Jellies** Foods that can be placed in a strong sugar concentration can be kept as preserves or jellies. The high concentration of sugar prevents most bacteria from growing. Some aerobic molds can grow on the top of these products so they must be kept tightly covered.
- **Salt-curing** Some meats can be preserved by placing large quantities of salt on them. The salt causes dehydration of active cells. Most salt-cured meat retains the heavily-salted taste. Salt-cured meats were common before freezing and refrigeration were convenient.
- **Refrigeration** Foods kept at low temperatures cannot support rapid growth of bacteria or mold. Refrigeration, however, does not stop food spoilage.
- **Quick-freezing** Those foods that can be frozen and still retain their desirable qualities after thawing can be stored by freezing. Freezing does not kill all the bacteria present, but does greatly retard their growth.
- **Dehydration** Removing the moisture from a food and then keeping it dry will prevent bacterial and fungal growth. Cereals and other naturally dry foods can be preserved by this method. Many foods cannot be preserved, but can be changed by dehydration (bananas into banana chips, grapes into raisins, fresh apricots into dried apricots).

Chemical Preservatives

The following list shows various chemicals and the foods to which they are added. The Food and Drug Administration (FDA) regards these chemicals as "Generally Regarded as Safe" (GRAS) when used in small amounts.

Sodium or calcium propionate
Bread, baked goods
Sodium benzoate
Carbonated beverages, margarine, juices, preserves
Sodium nitrite
Hams, bacon
Sorbic acid
Cheese, citrus products, salads
Sulfur dioxide
Dried friuts and vegetables
Formaldehyde (created within the food during the food-smoking process)
Meat, fish

Although used for many years, these chemicals are a source of controversy to some people.

- **Radiation** Placing the food in an airtight plastic container and then exposing it to radiation to kill all living things in the container will prevent food spoilage. In this relatively new process the radiation passes through the food but does not remain in it. Sealed radiation-preserved foods do not require refrigeration until they are opened because there is no living substance inside the container.
- **Pickling** Acids are used to preserve some foods. Pickles are cucumbers placed in vinegar (2% acetic acid) with other flavorings (like sugar or dill). A few other foods (even meats) can also be pickled.
- **Chemical preservatives** Added chemicals in some foods retard bacterial or fungal growth.

Review questions on page 236.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited.

There are no terms in this Facet which are listed in the Biological Terms section at the end of the chapter. The Facet presents the reasons behind common food-storage methods.

Students should be familiar with these food preservation methods. If they understand a few concepts about bacteria and food preservation methods, common kitchen practices will make sense.

In freeze-drying, food is frozen and placed in a vacuum to be dehydrated. Certain foods can be freeze-dried; others cannot.

Some new methods (like freeze-drying) prevent certain flavor and texture losses. Spray-drying, a process in which a liquid is sprayed into a heated chamber, is used to dehydrate foods like coffee, tea, milk, eggs, and fruit juices.

Candying fruits is a process similar to pickling and making preserves or jellies. Usually fruit is placed in a sugar solution and the water removed (often by slow-cooking at low heat). The sugar is absorbed into the fibers of the fruit in sufficient quantities that bacteria cannot actively grow without experiencing cytolysis. Honey does not spoil because of its high sugar concentration, resulting in cytolysis of cells that start to grow on it.

An extra activity for some interested students–research and present an oral or written report on some of the preservatives on the FDA's GRAS list. Sodium nitrite and formaldehyde are "hot" ones. The students should have little difficulty researching and finding opinions on both sides. Care must be taken not to "make a doctrine" out of foods and food fads. These should not become reasons for separation from a Christian brother or causes for a church split, as they have been (see pp. 547, 549).

The FDA is not faultless; it has been influenced by the food industry, but the good done by the FDA should not be overlooked.

In small quantities the GRAS preservatives are believed to be harmless to humans. Today, because some people believe they are harmful, many chemical preservatives are no longer being used. Baked goods and many boxed food mixes have chemical preservatives in them.

parasitic: para- (Gk. PARA, beside) + -sitic (SITOS, grain or food)

saprophytic: sapro- (Gk. SAPROS, rotten or putrid) + -phytic, -phyta, phyto-, -phyte (Gk. PHUTON, plant)

conjugation: con-, com- (L. COM-, together) + -jugation (JUGARE, to yoke)

Occasionally plates similar to the one on page 253 can be obtained from a hospital. A laboratory technician can explain the various media involved. Since bacteria grow only when certain materials are present, knowing what media they grow on can help in identifying them.

The box dealing with genetic transfer in bacteria can easily be skimmed or omitted if time is limited or interest is lagging.

Evolutionists sometimes cite transformation in bacteria as a method of introducing new genes into organisms. Note, however, that there are no new genes.

of are **parasitic*** (feeding on a living host). Most bacteria, however, are **saprophytic*** (feeding on dead organic matter). Saprophytic bacteria feed by secreting enzymes that digest external substances into soluble forms. These soluble materials then diffuse through the capsule and into the cell. Some of these digestive enzymes are important in the manufacture of cheeses and other useful substances.

Saprophytic bacteria are unable to manufacture all their nutritive materials and, therefore, require certain vitamins or other organic nutrients in their media. Experiments with mutation-inducing radiation or chemicals have produced bacteria whose offspring have reduced abilities to manufacture certain nutrients. The mutant offspring require these nutrient materials in their media. If these mutant bacteria are subjected to the same

Transfer of Genetic Material in Bacteria

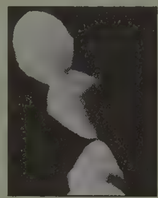
The transfer of genetic material from one bacterial cell to another is believed to be a relatively rare occurrence: only a few species of bacteria are known to do it naturally, and only a few have been forced to do it in a laboratory. The transferred genetic material may be a gene, a few genes, or a complete copy of the bacterial chromosome. Since there is no meiosis and no diploid cell or zygote formed, these genetic transfers are not considered true sexual reproductions.

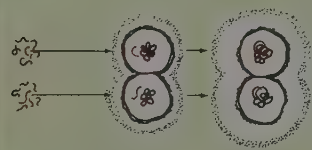
Conjugation* in bacteria is a natural process of genetic transfer. Certain strains of *Escherichia coli,* a common bacterium in the human intestine, possess the *F factor* (F^+). The F factor (a plasmid) is a gene in a bacterial cell which is not attached to the bacterial chromosome and permits the F^+ cells to form a *conjugation tube.*

A conjugation tube grows from an F^+ *E. coli,* and attaches to an *E. coli* which lacks the F factor (an F^- cell). Through the hollow conjugation tube a replicated F factor passes from the F^+ cell F^- cell. The F^- *E. coli* is now an F^+ *E. coli.*

In some other bacteria known to carry on conjugation, the entire bacterial chromosome passes through the conjugation tube. The donor bacterium always gives its traits to the receiving bacterium. There is no mutual exchange of characteristics in bacterial conjugation.

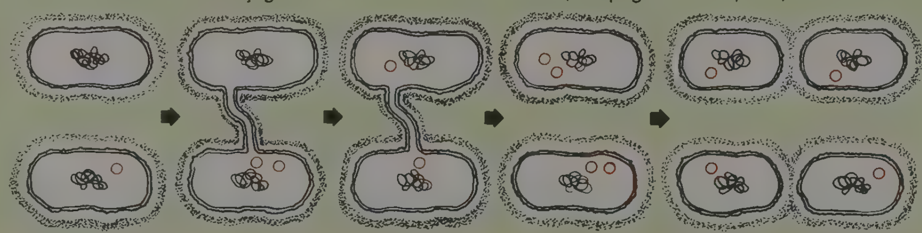
In **transformation,** another form of genetic transfer in bacteria, living cells take up the DNA of other bacteria. *Streptococcus pneumoniae* (see page 228) is known to transfer genes by transformation. Scientists can kill cells of the encapsulated *S. pneumoniae* and extract their DNA. If they place this DNA in a culture of non-encapsulated *S. pneumoniae,* these cells produce some non-encapsulated and some encapsulated bacteria. The gene for the capsule was absorbed by the living non-encapsulated cells, transforming them into the encapsulated variety.





Transformation: the gene for a thick sheath (red) is taken into a living cell from dead cells, causing the living cells to change their genetic make-up. Insert: S. pneumoniae

Today scientists often use bacteria for genetic engineering experiments and also use bacteria with genes planted in them to produce substances (see pages 163-64, 227).



Conjugation: the cytoplasmic DNA (red) passes through the conjugation tube from one cell to the next.

The Cyanobacteria
(The Blue-green Algae)

At one time the *blue-green algae* were considered plants. For a time they had their own phylum in the kingdom Monera (cyanophyta). Today scientists classify them as a group within one of the bacterial phyla and call them the **cyanobacteria***.

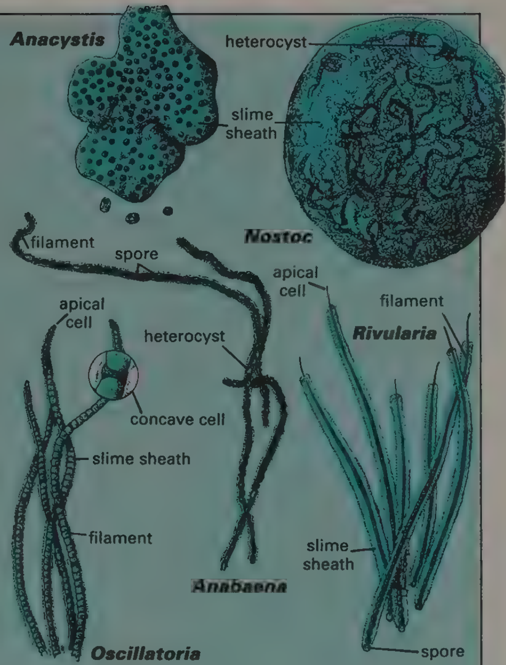
The cellular structure of the cyanobacteria is essentially the same as bacteria. Blue-green algae lack flagella, but many of them float in the water, and some (such as *Oscillatoria)* even appear to move by a type of sliding.

Cyanobacteria are often attached by their sheaths to underwater surfaces or to places which are constantly wet. Although most live in bodies of water, some algae live in the soil. Cyanobacteria reproduce by simple cell division. Some species are known to form spores, but none are known to reproduce sexually.

Although a few of the cyanobacteria are unicellular, most of them are colonial, forming **filaments** (long, thin strands of similar cells). In some species these filaments are branched. Some form colonies shaped like discs or globs. Often these colonies share slime coats, and sometimes groups of colonies form large gooey masses visible to the unaided eye.

Usually, within a colony all individual cells are the same. Some cyanobacteria, however, contain a **heterocyst*** (HET ur oh SIST), generally a single cell which may have different functions in different species. Some heterocysts appear to capture nitrogen gas from the environment and make it useful to the algae. Occasionally a heterocyst is a dead cell which permits easy *fragmentation* of the filament. In some species the heterocyst is alive, can carry on photosynthesis, and can divide, forming a new filament.

Cyanobacteria growing at the water's edge



All the cyanobacteria contain chlorophyll *a*, along with accessory pigments. Thus they carry on photosynthesis similar to that of autotrophs in other kingdoms. Many cyanobacteria contain a blue pigment (phycocyanin) and appear bluish green. About half of the cyanobacteria, however, are colorless, gray, green, yellow, orange, pink, purple, brown, violet, or red because of the presence or absence of other pigments.

Certain cyanobacteria, when in abundance, affect the taste or odor of water. Other blue-green algae produce poisons, making the water unfit to drink. When this happens to a farm pond, animals which drink the water may die.

type of radiation or chemicals, the next generation may have even more mutations and thus be capable of manufacturing even fewer nutrients. Thus, this new generation needs to be supplied with even more organic nutrients.

If evolution were true, increasing the mutation rate would produce organisms able to manufacture more and more substances. These organisms would require a smaller variety of nutrient materials. They would be more complex; they would have evolved. Experiments that increase the mutation rate, however, show the opposite. This is a case of change by mutation, but it is degeneration, not evolution.

cyanobacteria: cyano- (Gk. KUANOS, greenish blue) + -bacteria (rod)

heterocyst: hetero- (other) + -cyst (Gk. KUSTIS, bladder or pouch)

This box contains supplemental material which can easily be studied by most students. Omit this box if time is limited. The box presents the characteristics of cyanobacteria.

The terms **cyanobacteria, filaments,** and **heterocyst** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Bloom conditions of algae (pp. 275-76). The red tide organism coloring the water appears on page 274.

Some teachers find it more convenient to cover the cyanobacteria as a group of algae in Chapter 10. If this is done, be sure to stress that these algae are not eucaryotic as are the algae in the kingdom Protista.

This box contains supplemental material which should be studied by most students. Omit this box if time is limited. This box presents the characteristics of rickettsias, spirochetes, and mycoplasmas and the primary diseases they cause.

The terms **rickettsia, spirochete,** and **mycoplasma** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

A mild rickettsial disease in humans is *Q fever.* The natural hosts of the organism are cattle, sheep, or other animals. The symptom is a temporary fever, which is often recurring until the person has completely recovered from the disease. It is rarely fatal.

Rickettsias, Spirochetes, and Mycoplasmas

Monera contains several distinct groups of organisms. Three which are significant because of the pathogens they contain are *rickettsias, spirochetes* and *mycoplasmas.* With rare exceptions these are *obligate parasites*–they must have a living host.

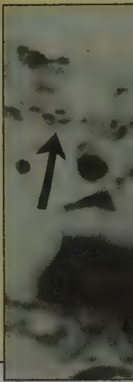
The Rickettsias

Dr. Howard T. Ricketts was the first person to describe a small bacterium in the blood of people suffering from Rocky Mountain spotted fever. In 1910 Dr. Ricketts saw a similar organism in the cells of people with typhus fever and in the lice which carry the disease to humans. During his studies Dr. Ricketts contracted typhus and died. This group of organisms was named in his honor.

The **rickettsias** (rih KET sih uz) are *intracellular parasites:* they live inside cells. Rickettsias can grow and divide rapidly, but they are highly specific, growing only in certain cells. They do not form spores and do not reproduce outside living cells. Most substances in the cytoplasm of their host cell easily penetrate their cell walls and membranes.

Rickettsial diseases usually cause fevers, rashes, and blotches under the skin. The blotches are the result of the rupturing of damaged small blood vessels. Once a person recovers from a rickettsial disease, he is usually immune to its harmful effects even though his cells may still contain the organism. Such a person may host the pathogen without being sick himself.

Typhus fever, caused by a rickettsial organism, is one of the diseases that has claimed the most human lives. Man is the natural host for this dis-

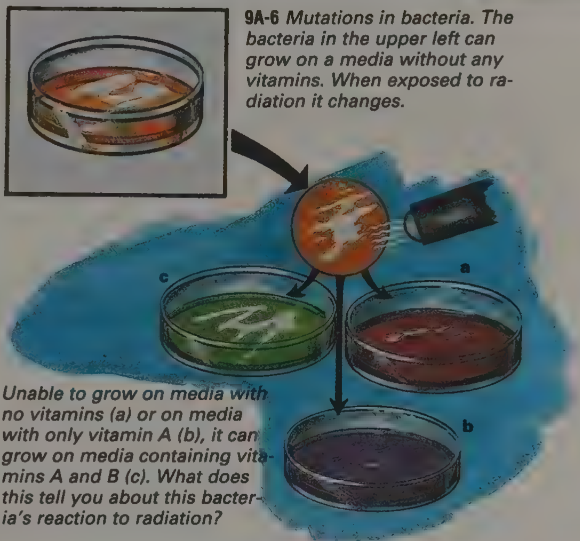


A strain of typhus fever became known as "trench fever" during World War I because it was passed readily among the soldiers in the close quarters of the trenches (above). The Rocky Mountain spotted fever rickettsia in human cells (right).

In addition to the terms presented here, the main considerations should be the two antievolutionary concepts. Explain why mutations of bacteria make bacteria more dependent on their environment. This should help students grasp the concept of "natural devolution." Evolution must be a "making-more-complex" process, and no random form of mutation that affects individual genes has been observed to do this. If evolution were possible, it could be duplicated here, on the bacterial level. Observation seems to prove the opposite.

Parasitic bacteria usually need to absorb nutritive substances without digesting them. These bacteria need many nutritive substances in their media. Some bacteria and similar organisms are **obligate parasites;** they require the presence of living tissue in order to grow. Parasitic bacteria lack many of the systems for organic synthesis that the saprophytic or autotrophic bacteria have.

Most evolutionists speculate that bacteria were the first living things. If evolution were true, the simplest organisms would have evolved first. The simplest would be the obligate parasites, the ones with the least complex biological systems. The autotrophic bacteria, those with the most complex biological systems, would have evolved from the simpler parasitic types. Parasites, however, cannot support themselves. Considerable evolution of a previous organism to serve as their host would be essential.



9A-6 *Mutations in bacteria. The bacteria in the upper left can grow on a media without any vitamins. When exposed to radiation it changes.*

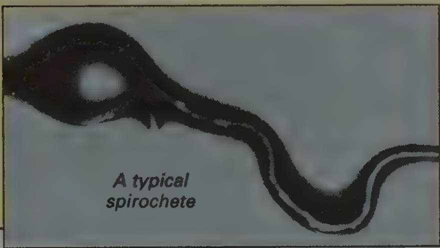
Unable to grow on media with no vitamins (a) or on media with only vitamin A (b), it can grow on media containing vitamins A and B (c). What does this tell you about this bacteria's reaction to radiation?

ease, and human body lice and human head lice pass it from one person to the next. The typhus fever rash spreads over the body except for the soles of the feet and palms of the hands. Following a fever which makes the victim sluggish, death may occur within ten days. Drugs can control the disease, but control of the lice which carry the disease is the best preventative.

Rocky Mountain spotted fever was first recognized in the American West, but is more common in the eastern states. It is carried by ticks from small mammals (rodents, rabbits, dogs) to man. About two weeks following the tick bite, the person develops a fever, headache, chills, and rash; the disease is rarely fatal.

The Spirochetes

Most **spirochetes*** (SPY ruh KEETS) are larger than the average bacterium and many are corkscrew shaped. Some spirochetes are free-living and normally inhabit the mouths, intestines, and reproductive organs of humans and animals. Some are believed to be nonpathogenic. Some spirochetes are found in sewage and in decomposing plant materials.



A typical spirochete

Spirochetes lack flagella but have flexible cell walls which permit them to move by contracting their coils. Many are highly specific as to their environment. None are known to form spores. Lyme disease, yaws, infectious jaundice, syphilis, and relapsing fever are a few of the diseases caused by spirochetes.

The Mycoplasmas

Mycoplasmas* (MY koh PLAZ muhz) were discovered about the turn of the century as pathogens in the membranes around the lungs of cattle. Other mycoplasmas have since been found living harmlessly in the human mouth, nasal passages, and urinary tract. Several animal and plant diseases have been attributed to mycoplasmas. Atypical pneumonia, arthritis, and infections of the urinary tract in humans have been associated with mycoplasmas. Mycoplasmas lack a cell wall and thus can assume a variety of shapes. They are highly specific regarding the solute concentrations they can tolerate.

spirochetes: spiro- (L. SPIRA, a coil or a twist) + -chetes (Gk. KHAITE, long hair)

mycoplasmas: myco- (Gk. MUKES, fungus) + -plasmas (to mold)

Outbreaks of typhus fever are common whenever people are closely grouped and proper precautions not taken: military campaigns, famine, and civil disruptions. It also has been spread through schools and hospitals because of a lack of sanitation. Actually, the term *typhus fever* has been applied to several similar diseases caused by a species of *Rickettsia*, not just *R. prowazekii.*

Typhoid fever is caused by a bacterium (see p. 251) and is named "typhus-like" because of the similarity of symptoms. The organism enters the skin, not from the bite of lice, but from their rickettsial-infested feces being rubbed into openings in the skin when the host scratches the lice bites.

There are drugs that can be used to treat people with Rocky Mountain spotted fever. The rash begins on the extremities and forehead and spreads to the trunk. Ticks spread the disease among animals, which usually do not suffer major problems from the rickettsial parasite.

Syphilis is discussed on pages 644-45.

Bacteria and oxygen

Louis Pasteur demonstrated that some bacteria can grow without (and are actually inhibited or destroyed by) free oxygen. Those organisms which grow only without free oxygen are **obligate anaerobes,** and those which grow only with free oxygen are **obligate aerobes.** Many bacteria can grow as either aerobes or anaerobes; they are **facultative anaerobes.**

Many bacteria which grow in the depths of lakes and oceans or the ooze of swamps are anaerobic bacteria. Many of the bacteria used to make cheese, yogurt, sauerkraut, buttermilk, alcohol and other products are anaerobic bacteria. Some anaerobic bacteria are pathogenic, causing diseases such as lockjaw (tetanus), gas gangrene, and food poisoning. Anaerobic bacteria carry on various types of fermentation and form different products, including lactic acid, alcohol, methane, carbon dioxide, hydrogen sulfide (a gas which smells like rotten eggs), acetic acid (vinegar), citric acid, and ammonia. Many bacterial names indicate their fermentation products *(Lactobacillus* makes lactic acid; *Acetobacter* makes acetic acid).

Conditions of bacterial growth

For bacteria to grow and divide, several environmental factors must be within the bacteria's optimal range. These include the following:

- *Moisture* Although many are protected by their capsules during temporary dry periods, all bacteria require moisture to grow. Some bacteria grow best submerged in fluids.
- *Temperature* Enzyme systems of different bacteria operate at different temperatures. Some bacteria grow near freezing and some at high temperatures, but most bacteria thrive in temperatures from 27° C to 38° C (80° F to 100° F). Human

Answers–Review Questions 9A-2 *(p. 236)*

1. Cell division occurs without mitosis; the chromosome replicates, and daughter chromosomes separate; invagination of plasma membrane forms daughter cells; they grow to full size within minutes.
2. **(1)** Endospores form within the plasma membrane; several layers of hard materials form around the nuclear area and metabolism is reduced. **(2)** Activities decrease (reduced metabolism).

*3. **(1)** In conjugation, a conjugation tube forms from the F^+ to the F^- bacteria. Replicated F factors pass from male to female, the donor bacterium giving the traits to the receiver bacterium. **(2)** In transformation, living cells absorb the DNA of other bacteria from the environment.

4. **(1)** Photosynthetic bacteria contain bacteriochlorophyll, which is purple, red, or brown instead of green. These allow photosynthesis in darker areas than plants could normally function in. **(2)** These bacteria obtain hydrogen from hydrogen sulfide instead of water. **(3)** Oxygen is usually not a product.
5. **(1)** Autotrophic–photosynthetic and chemosynthetic; **(2)** heterotrophic–parasitic and saprophytic.

*6. **(1)** Both are procaryotic, have a cell wall, and produce a slimy sheath. **(2)** Most cyanobacteria are colonial, forming filaments; some contain heterocysts, and they contain chlorophyll *a* and accessory pigments; cyanobacteria carry on oxygen-producing photosynthesis, while the photosynthetic bacteria usually produce other chemicals.

7. **(1)** Obligate aerobes can grow only in the presence of free oxygen. **(2)** Obligate anaerobes can grow only without free oxygen. **(3)** Facultative anaerobes grow best as aerobes but can function as anaerobes.

Suggestion: Use the *Conditions of bacterial growth* section as a review of bacterial characteristics already discussed.

Visual 9A-3 can be used to present material regarding bacteria's source of oxygen and to review other characteristics of bacteria. When using the chart, stress the variety of bacteria. Conditions for soil bacteria would not be the same as those for pathogenic bacteria.

pathogenic bacteria grow best at body temperature 37° C (98.6° F) and have a range of only a few degrees in which they can grow. Most bacteria have a range of about 30° C in which they can grow.

❑ *pH* Although many bacteria can grow in a nearly neutral condition, the pH of the environment is critical to their existence. Raising or lowering the pH can destroy one kind of bacteria but cause ideal conditions for another.

❑ *Nutrition* The food source for heterotrophic bacteria must not only meet the energy needs but must also supply the materials necessary for bacterial biosynthesis. For some heterotrophs, especially the parasites, the proper food source is highly specific. Even though photosynthetic bacteria obtain their energy from light, they often require various substances (inorganic and occasionally organic, such as vitamins) in order to grow. Chemosynthetic bacteria require specific chemicals as their energy source.

Although bacteria live in almost every known environment, what is advantageous for one species may kill another species. Since each species of bacteria requires a specific set of environmental conditions in order to grow and reproduce, bacteria exhibit a high degree of specificity. In other words, they are *highly specific* regarding the environment in which they can grow and multiply.

Biological Terms

microbiologist
bacteria
decomposer organisms

Bacterial Shapes, Sizes and Colonies
coccus, (pl., cocci)
bacillus, (pl., bacilli)
spirillum, (pl., spirilla)
nuclear area
mesosome
capsule

Bacterial Growth and Reproduction
endospore
chemosynthetic
pasteurization
parasitic
saprophytic
conjugation
transformation
cyanobacteria
filaments
heterocyst
rickettsia
spirochete
mycoplasm
obligate parasite
obligate anaerobe
obligate aerobe
facultative anaerobe

Answers begin on page 235.

Review Questions 9A-2

1. Describe asexual reproduction in bacteria.
2. Describe two methods bacteria use to survive periods of unfavorable conditions.
3. Describe two methods of genetic transfer in bacteria.
4. List several differences between bacterial photosynthesis and photosynthesis in plants.
5. List the two types of autotrophic and the two types of heterotrophic bacteria.
6. List several common characteristics that the cyanobacteria share with other bacteria and several characteristics that separate the cyanobacteria as a distinct group.
7. Describe and compare obligate aerobes, obligate anaerobes, and facultative anaerobes.
8. When culturing a particular bacterium, what conditions must one consider in order to have it survive and grow?
9. Differentiate between an obligate parasite and an intracellular parasite.
10. Describe mycoplasmas, rickettsias, and spirochetes. List several diseases caused by organisms in each of these groups.

Facet 9A-2: Controlling Bacteria, page 231

1. What are the two basic methods of controlling food spoilage-bacteria? List several household or commercial practices and tell how they illustrate these methods.
2. Describe the process of pasteurization. Why must milk be pasteurized if it is not to be consumed immediately.

8. **(1)** Moisture must be sufficient (varies with type of bacteria). **(2)** Temperature must be between 15°C and 38°C (also varies); some exist at extreme temperatures (0°C or 350°C). **(3)** pH is critical for existence; most grow in nearly neutral pH. **(4)** There must be a sufficient food source. **(5)** Photosynthetic bacteria require light, but some can be heterotrophic in absence of light.

*9. An obligate parasite cannot live without its host. An intracellular parasite is one which lives inside cells. A parasite can be both obligate and intracellular.

*10. **(1)** Mycoplasmas lack cell walls, have various shapes, and are highly specific to solute concentration (e.g., atypical pneumonia, arthritis, and urinary infections). **(2)** Rickettsias are intracellular parasites that have cell walls and are spherical or short rod-shaped (e.g., typhus fever, Rocky Mountain spotted fever). **(3)** Spirochetes have a bent or corkscrew shape; some are free living, some live in the digestive and reproductive organs. They lack flagella but have flexible cell walls; they do not form spores (e.g., lyme disease, yaws, jaundice, syphilis, relapsing fever).

*From a box.

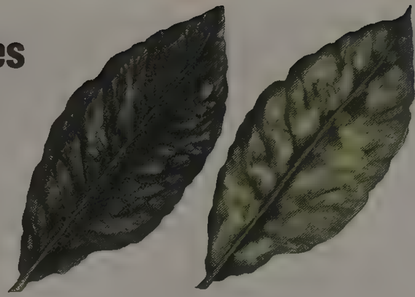
Answers–Facet 9A-2

1. **(1)** Destroy bacteria present, and seal food in containers to prevent entrance of bacteria (canning). **(2)** Place food in an environment that is unfavorable for bacterial growth (freezing, heating, refrigeration, dehydration).

*2. In pasteurization, milk is heated to a temperature that destroys most bacteria (all pathogenic strains) and then cooled. If no new bacteria are introduced and the milk is kept cool, it will keep longer than it would have without pasteurization.

*From a box.

9B-Viruses



9B-1 *A normal tobbaco leaf (left) and one infected with TMV (right).*

Viruses have plagued mankind for a long time. Some of the earliest recorded diseases and their prescribed remedies were for viral diseases. After the "germ theory of disease" came into prominence during the late 1800s, various protozoans and bacteria were isolated and demonstrated to be the "germs" that caused various diseases. Many diseases, however, defied early attempts to isolate a pathogenic organism.

Both Edward Jenner, who dealt with smallpox, and Louis Pasteur, who dealt with rabies, formulated successful vaccinations for these diseases. They thought they were working with bacteria or similar organisms that had not yet been isolated. But even today we cannot isolate a pathogenic *organism* for these and many similar diseases. The reason is that they are not caused by *organisms;* they are caused by viruses.

Students should remember Pasteur from pages 22 and 230.

The discovery of viruses

In 1892, a Russian biologist, Dimitri Iwanowski, worked with tobacco mosaic, a disease which causes light green patches on tobacco leaves and stunts leaf growth. Iwanowski passed the juice from diseased leaves through an unglazed porcelain filter. Such a filter is so fine that it permits only dissolved substances to pass; not even the smallest bacteria can go through. The resulting fluid, when examined under a microscope, contained no visible particles. Nonetheless, when this juice came in contact with a tobacco leaf, it caused tobacco mosaic disease. Iwanowski assumed that the fluid contained a poison made by a bacterium. A few years later the term *virus,* the Latin word for poison, was assigned to the unknown agent which caused the disease.

In the mid-1930s, Wendell Stanley, working at the Rockefeller Institute, isolated the actual virus. He reduced the juice from about a ton of infected tobacco mosaic leaves to about one spoonful of crystals. These crystals could be kept in a dry, airtight jar for extended periods of time. They had no metabolism; therefore, they were obviously an inert chemical. But when they were placed in contact with a living tobacco leaf, they caused tobacco mosaic disease. Stanley was awarded the Nobel Prize in chemistry in 1946 for isolating and purifying the **tobacco mosaic virus (TMV).**

There is nothing unusual about a disease caused by a chemical. Various poisons and irritants affect cellular metabolism, resulting in disease and death. A certain amount of cyanide (a chemical poison) given to a laboratory animal will kill it. Careful examination of the animal's body will reveal only the amount of cyanide given to the animal. The animal's body does not make more of the poison.

A virus, however, is very different. A tobacco leaf exposed to a tiny amount of TMV will develop the disease and die. Later if the TMV is extracted from the leaf, much more will be found than was placed on the leaf. TMV apparently "grows and reproduces" when placed on a tobacco leaf. How? Is TMV alive, or is it a "dead chemical?" Does the *leaf* make more TMV? Does TMV alter the genes of the leaf cells? Does TMV supply genes to the cell to have more TMV made? Controlled experiments and careful observations with the electron microscope have supplied many of the answers.

Although Dr. Wendell Stanley is not pictured, it is suggested that the students be familiar with his accomplishments.

Visual 9B-1 can be used to teach the size relationships of various organisms that have been studied.

Review Questions 9B-1

1. Give the contributions to the study of viruses made by (a) Dimitri Iwanowski and (b) Wendell Stanley.
2. In what ways is a virus different from a chemical poison?

Answers begin on page 238.

9B–Viruses

Notes–Chapter 9B

Viruses are commonly talked about but frequently misunderstood. A basic understanding of what a virus is and how it operates is essential for people to understand the world in which they live. Much of the concern about AIDS and other viral diseases will be lessened (and some strengthened) by a thorough understanding of viruses. (AIDS is covered in detail in Chapter 21B.)

The first chart of diseases appears on page 243. There are several of these charts

Objectives–Chapter 9B

- ❑ Describe the physical properties of a virus when it is not in contact with a cell.
- *❑ Describe Dr. Edward Jenner's work with smallpox vaccinations.
- ❑ Describe the lytic cycle of a virus.
- ❑ Explain what is meant by viral specificity.
- ❑ Describe a latent virus.
- ❑ Tell what is meant by a persistent viral infection and a transforming virus.
- ❑ Describe what interferon does.
- ❑ Discuss viruses as living versus nonliving things.
- ❑ List and describe several viruses that directly or indirectly affect man.

*From a Facet.

vaccination: (L. VACCINUS, of cows) *From cows because the first vaccine was prepared from the cowpox virus.*

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. The Facet presents that people dealt with viral diseases long before they knew what viruses were; Jenner administered the first successful vaccination; some viruses are similar enough that immunity to one means immunity to another; and that smallpox may not be completely eradicated.

The term **vaccination** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Jenner, although not the first to propose this method of developing immunity, was the first to actually experiment with it.

Some historians have estimated that more American Indians died of smallpox–the white man's disease–than were killed by white men's bullets. The white settlers contracted the disease at a younger age, when they were able to fight it off with proper treatment; so many white men had immunity. Indians, with no immunity, living close together, were very susceptible to widespread outbreaks of the disease.

Other material about vaccinations is found on pages 574-76.

9B-1 FACETS OF BIOLOGY

Smallpox–A Plague of the Past?

Smallpox plagues have affected man for centuries. But in the late 1700s in Europe smallpox epidemics swept through cities and caused thousands of people to break out in red *pustules* (fluid-filled blisters). Most who contracted the disease died. Any who recovered had permanent scars but were *immune* to (would not again contract) smallpox.

Dr. Edward Jenner, an English physician, noted that people who lived in the country, and especially those who worked around dairy cattle, appeared to be immune to smallpox. He observed that most farmers and dairy workers had previously experienced a mild disease called *cowpox*. This disease caused a small pustule, usually on the hands of those who milked the cows, which healed and left a small scar.

In 1796 during a severe smallpox epidemic, Mrs. Phipps brought her son, James, to Jenner. She feared that James had contracted smallpox and had heard that Jenner was working on a cure. On May 14, 1796, Jenner took matter from a cowpox pustule on the hand of a dairymaid and inoculated James by applying the matter to two shallow cuts he made on the boy's arm. A pustule developed, formed a scab, and then disappeared, leaving only a scar.

Was the boy now immune to smallpox? In June of the same year Jenner again inoculated his patient, this time using matter from a smallpox pustule. For two anxious weeks Jenner watched James for signs of the disease. None developed. Later in the year, he inoculated him again with material from a smallpox pustule, but James did not develop the disease.

Jenner wrote a paper describing what he called a ''vaccination'' against smallpox. Today we know that a **vaccination*** is not a cure for a disease but is a method of developing an immunity by exposing a person to either a weakened form of the disease or a similar disease.

At the time of Jenner's work most people did not understand the idea of vaccinations. People organized anti-vaccination campaigns. Cartoons of the time showed people with cow heads, tails, legs, and hoofs growing out of their bodies where they had been vaccinated.

Jenner did not know what caused smallpox or cowpox. About 150 yr. after his vaccination of James Phipps, it was discovered that smallpox and cowpox are caused by similar viruses. When a person develops an immunity to one, he also becomes immune to the other.

About 200 yr. after Jenner's first vaccination, the World Health Organization (an agency of the United Nations) announced that smallpox had been eradicated. Since there is an effective vaccine against smallpox and the only known place the virus can exist is in humans, it is theoretically possible to eliminate the disease. If everyone were vaccinated against the virus, there would be no place for the virus to exist, and that would be the end of smallpox.

The task of vaccinating over 4.5 billion people proved impossible for even the United Nations. They adopted the idea of vaccinating everyone near an outbreak of smallpox. After a few years there appeared to be no more major outbreaks of smallpox, and in 1980 the World Health Organization certified that smallpox was the first major human disease to be completely eliminated. Routine vaccinations stopped. Today you do not need a smallpox vaccination to attend school or to travel to other countries.

Some scientists doubt that smallpox has been totally eradicated. To say that no one is suffering

Fear of vaccinations inspired cartoons like the one below.

throughout the book. See information regarding them in the Notes for Chapter 9C (p. 245).

Facet–Chapter 9B

This Facet is interesting because of the historical significance of smallpox and the current claims of smallpox eradication. It should take only a few minutes to cover the Facet.

Answers–Review Questions 9B-1 *(p. 237)*

1. (**a**) Dimitri Iwanowski worked with the fluid containing TMV. He assumed that it contained a poison from a bacterium. The term *virus* was given to denote this ''poison.'' (**b**) Dr. Wendell Stanley isolated the virus substance. He was awarded the Nobel Prize in chemistry for isolating TMV.
2. A virus grows and reproduces under proper conditions; a chemical poison does not reproduce.

Edward Jenner innoculating James Phipps with matter from the cowpox pustule of a dairymaid's hand to develop an immunity in the boy. Jenner first called the procedure a vaccination.

from smallpox is a universal statement, the kind which science cannot make. There may be a remote area where smallpox does exist, or it may exist in a nonvirulent form which could mutate into the virulent form. Some people fear that there may be a smallpox epidemic in the future. Since most children are currently not being vaccinated, a growing segment of the population is susceptible. If the virus is in a remote area and spreads to a populated area, or if a nonvirulent form mutates into a virulent form, a smallpox epidemic could sweep through a population causing a plague.

Review questions on page 242.

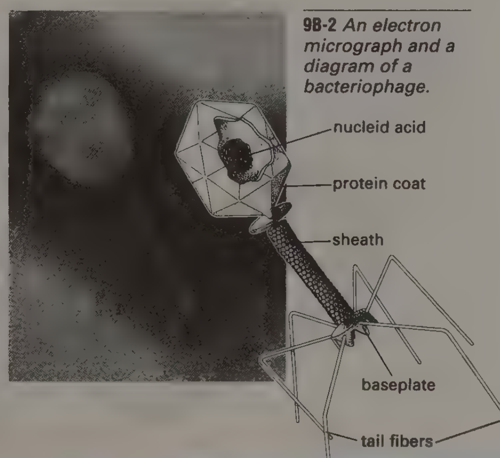
Structure and Functions of Viruses

Viruses consist of a molecule of DNA or RNA and a **protein coat.** They have no cell membrane, cytoplasm, or organelles of their own. Essentially viruses are chromosomes. The tobacco mosaic virus consists of a spiral of RNA covered by a protein coat made of repeated subunits.

The TMV RNA contains only about 6,000 bases, enough for a dozen small proteins. When stretched out, the 6,000 bases in a TMV are just over 1.5 μm long. By comparison, the stretched-out DNA in an average bacterium is about 1,000 μm long, which is about the length of the stretched out DNA of the smallest human chromosome. When coiled, however, the TMV is about 300 nm long, while the length of an average bacterium is about 1,000 nm and that of a human red blood cell is 7,500 nm.

Some viruses have several different protein structures in their coats. The **bacteriophage*** (a virus that infects certain bacteria) illustrated in figure 9B-2 is such a virus. These protein structures probably help the virus to enter the bacterial cell. The DNA in the head portion of a bacteriophage contains about 200,000 base pairs. The bacteriophage can produce dozens of different proteins, more than TMV, although the virus particles are about the same size. The more complex structure of the protein coat of the bacteriophage

bacteriophage: bacterio- (rod) + -phage (to eat)



9B-2 *An electron micrograph and a diagram of a bacteriophage.*

lytic: (noun form is -lysis) (Gk. LUEIN, to loose or break apart)

Visual 9B-2 can be used to help teach the lytic cycle. Colored pens are helpful to delineate which is viral and which is bacterial, as in the text illustrations.

demands a wider variety of proteins than the simple recurring subunits of the TMV.

The lytic cycle

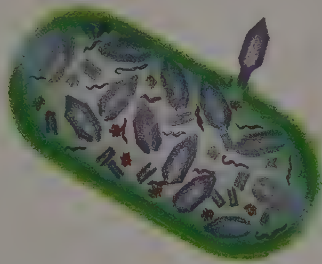
The ability of a pathogen to affect cells is called **virulence** (VIHR yuh lunce). If the virus does not affect a certain type of cell, the virus is *nonvirulent* for that cell type. TMV, for example, is nonvirulent to human cells. You could eat TMV with little danger. A highly *virulent* virus, however, can enter a cell, produce hundreds of virus particles, and destroy the cell in less than an hour.

Scientists call the activity of a virulent virus the **lytic*** (LIT ik) **cycle.** We will illustrate the lytic cycle of a virulent bacteriophage. The lytic cycle, although slightly different for various viruses, generally follows these steps:

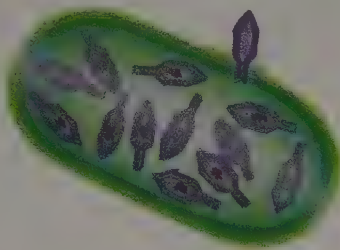
❑ *The virus attaches itself to the cell.* The various coat proteins of some viruses aid in the attachment to the host cell. Some virus particles are engulfed by the cell.

❑ *The DNA (or RNA) of the virus enters the cell.* Often the empty protein coat remains outside the cell. In some viruses the protein coat may enter the cell and then release its nucleic acid.

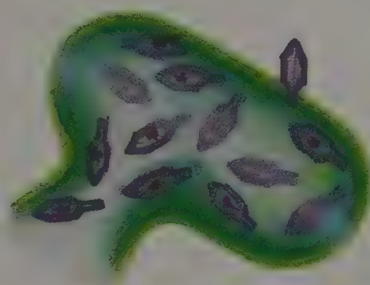
❑ *The DNA (or RNA) begins to transcribe and replicate.* Using the cell's chemical machinery, the virus begins to manufacture mRNA, multiple copies of the viral nucleic acid, and proteins.



❑ *Virus particles form within the cell.* The virus proteins form coats around the replicated viral DNA (or RNA), producing new viruses.



❑ *The cell bursts, releasing the newly-formed virus particles.* Cellular machinery and supplies used by the virus have not been replaced, and soon the cell dies. By the *lysis* process, the cell ruptures, releasing new virus particles which can then begin the lytic cycle in other cells.



Certain bacteriophages, as well as the viruses causing human polio and influenza, are relatively virulent, forcing the entire cell metabolism to make new viruses. When a virulent virus particle infects a cell, it can sometimes produce hundreds of viruses in as little as 30 min. Each of those new virus particles can infect another cell and multiply into hundreds in each infected cell. It is easy to see how the symptoms of certain viral diseases can be produced very quickly.

Latent viruses

Not all viruses begin to destroy the cell immediately after entering it. A **latent virus,** for example, enters a cell and may remain inactive for long periods of time. In an inactive state some latent bacterial viruses attach to the bacterial chromosome and replicate along with it when the cell divides. In time a good portion of the bacterial population may have the virus. In animal and human cells it appears that many latent viruses reproduce each time the cell divides so that the new cells all have the virus in them.

When a certain stimulus (such as ultraviolet radiation, certain chemicals, or an unknown agent) is applied, the virus becomes virulent, enters the lytic cycle, and destroys the cells. Since the virus may be in a large number of cells before the stimulus is applied, a large area may be affected all at once. The viruses then enter other cells and, unless the stimulus is still present, again become inactive.

The *herpes simplex* virus affects humans. It produces small fluid-filled sacs, commonly called fever blisters or cold sores. These blisters, followed by scabs on the skin, usually form around the lips near the nose. Herpes simplex is believed to be a latent virus; it can exist quietly in the nerve cells for long periods.

In different people the following stimuli may cause the herpes simplex virus to leave the nerve cells and become virulent to skin cells: some foods, skin dryness, sunlight, burns, or injury. In most susceptible people, the body conditions associated with a severe or prolonged cold appear to change the virulence. Some people are immune or can develop an immunity to the virus.

Other kinds of viruses

Viruses can also cause *persistent infections*. In a persistent viral infection the host cell does not go through lysis, but slowly releases virus particles. This type of viral infection may not destroy the cell, but it does hamper the cell's metabolism. Even stress could harm the organism if enough cells contain persistent infection virus.

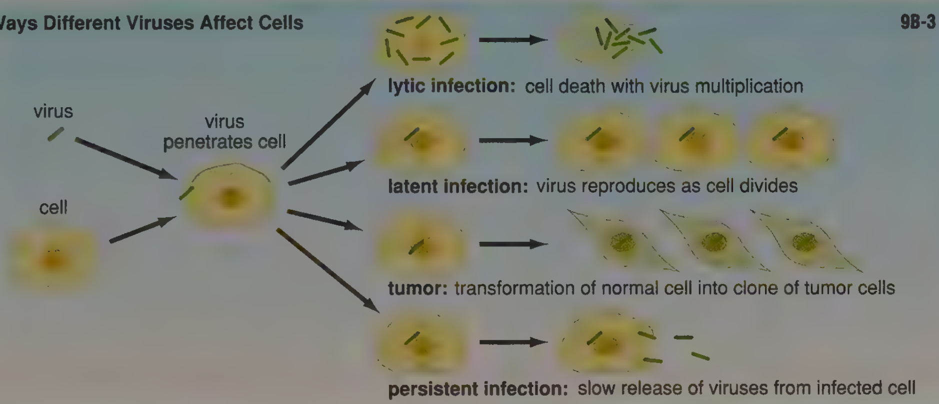
Some viruses are *transforming viruses*. These viruses transform their host cells by adding new genetic information. They significantly change the cell's metabolism but do not destroy the cell. The transformed cell, however, is not a productive cell in the organism's body.

An example of a transforming virus is one that causes certain warts in humans. The wart virus

About one-third of the population is exposed to herpes simplex type 1 by adulthood.

Another strain, herpes simplex type 2, affects the skin and occasionally other structures around the reproductive organs. It is considered a venereal disease. Cold sores or fever blisters caused by herpes simplex are usually a minor problem. If they form in the eyes, however, blindness can result.

Ways Different Viruses Affect Cells 9B-3



enters the skin cell and transforms it into a wart cell. As the transformed cell grows and divides the wart grows. In time the wart reaches a certain size, and the cells stop growing and dividing. Some tumors are caused by viruses which transform the cells they infect.

Review Questions 9B-2

1. Describe the structure of a virus particle.
2. Describe the lytic cycle.
3. What is the difference between a virulent virus and a latent virus?
4. List and describe two effects, other than the lytic cycle, which some viruses may have on cells.

Facet 9B-1: Smallpox - A Plague of the Past, pages 238-39

1. What is the relationship between smallpox and cowpox?
2. Who was Dr. Jenner and what is he credited with doing?

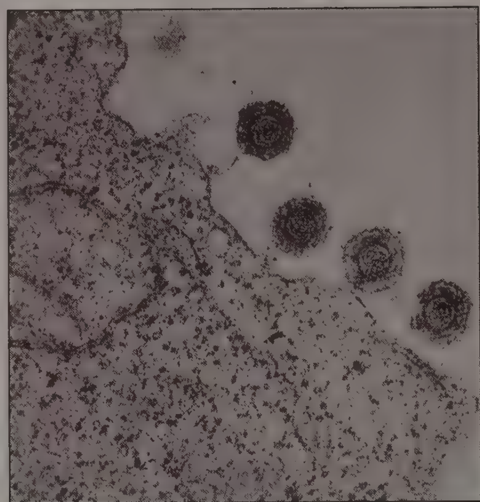
Some animal cancers are caused by viruses. Only a few human cancers are suspected of being caused by viruses (a type of adult leukemia, Burkitt's lymphoma or Epstein-barr virus, a type of liver cancer, some cervical cancers, and some skin cancers). The data supporting the viral cause for human cancers is somewhat circumstantial. Experimentation is difficult. More on tumors and cancer is found on pages 254, 257-58.

See AIDS virus and disease discussion (p. 571).

Viral diseases

Most viruses are highly specific regarding their host cells. It appears that a virus particle in contact with the wrong type of cell either lacks the mechanisms for entering the cell or once in the cell, lacks the mechanisms for affecting its metabolism. This virus would most likely be destroyed by the cell or released as a waste product.

Most viruses are thus limited not only to one type of organism but to one type of cell in that organism. Smallpox, chicken pox, and measles usually affect skin cells. Rabies and polio attack cells in the nervous system. Influenza and the common cold are usually viral infections of the respiratory system. A few viral diseases, however, like rabies and cowpox, can affect similar cells in different organisms.



9B-4 *An electron micrography of the AIDS virus.*

The "First Living Thing"?

Since a virus is a chemical which can use cellular parts to produce more of itself, some evolutionists have claimed that viruses are the step between living and dead organisms. Today most scientists agree that viruses could not be the evolutionists' "first living things." If a virus were to exist in an environment which completely lacked living cells, it could not grow or reproduce. It would just exist until chemicals, heat, or something else destroyed it. Viruses must have come into existence at the same time as cells (at creation) or later at the curse (Gen. 3:19).

The blood can carry various poisons released by virus-infected cells to other areas of the body. These transported poisons often cause the symptoms of the disease to be widespread, even though the actual infection may be in a limited area. Thus flu viruses in cells of your respiratory system can cause muscle soreness, headaches and nausea, even though the cells of these areas have no viruses in them. The blood can also carry many types of virus particles from one area to another. A viral infection, therefore, is often found in areas of the same tissue throughout the body.

Answers–Review Questions 9B-2

1. A virus consists of a strand of RNA or DNA and a protein coat.
2. **(1)** The virus attaches to a cell. **(2)** The DNA (or RNA) enters the cell. **(3)** The DNA (or RNA) begins to be transcribed and to replicate. **(4)** The cell begins to manufacture virus proteins. **(5)** Virus particles form within the cell. **(6)** The cell ruptures and releases newly formed virus particles.
3. A virulent virus enters certain cells, reproduces, and injures cells immediately. A latent virus does not destroy cells immediately; it may remain inactive for long periods of time.
4. Some viruses cause persistent infections. In these the cells are not destroyed but changed to produce the virus. Transforming viruses do not kill the cell but change the cell into a different kind of cell (tumor).

Answers–Facet 9B-1

1. They are both caused by a similar virus.
2. Dr. Jenner took matter from a cowpox pustule and injected it into James. A pustule developed, formed a scab, and disappeared. Jenner later inoculated James with smallpox; no disease developed. James was immune to smallpox. Jenner had performed the first vaccination.

Human Viral Diseases

Chicken pox and shingles The same virus causes chicken pox in children and shingles in adults who once had chicken pox. One of the herpes DNA viruses, the chicken pox virus, is very contagious and is probably spread by droplets and physical contact. In the bloodstream it spreads causing a body rash and a mild fever. Adults may develop more serious symptoms from chicken pox. After the chicken pox stage the virus can become latent in nerve cells. Years later the virus may move from nerves to the skin and cause small, often painful sores called shingles. No vaccine is available.

Common cold The common cold is a leading cause of illness. There are many different kinds of viruses that cause the common cold, and each one is different enough to prevent us from developing immunity to the cold. It appears that the common cold is not highly contagious; in one study only about 35% of those directly inoculated with the virus got a cold. Physical conditions (stress, amount of rest, other illnesses, etc.) appear to be significant regarding whether or not a person gets a cold. Direct contact with the infected person or his secretions (such as soiled tissues) appears to be more important in spreading the disease than airborne droplets.

Infectious hepatitis This disease is spread by contaminated food or water. The virus can withstand mild heat, dryness, and chlorination of water. The early symptoms include fever and chills, loss of appetite, headache, muscle pains, jaundice (yellow color of the skin), and abdominal pain and swelling. Once the person recovers, he is immune. The disease causes the liver cells to lose the ability to function, but following recovery (which may take months) the liver can regrow.

Influenza In the U.S. influenza or flu is among the leading causes of illness. The flu is caused by a virus made of a protein coat covering up to 8 pieces of RNA. It is transferred by airborne droplets. The infection begins in the upper respiratory tract and symptoms include soreness and redness of the nose and throat, a dry cough, a fever, muscle soreness, headaches, and nausea. Several major different kinds of flu exist. Each RNA fragment can mutate to form a new strain of flu, and sometimes the RNAs from different kinds appear to combine, forming new strains. These new strains may have different protein coats, the host cells they invade may be changed, or its virulence may be altered. When you recover from a particular flu, you develop a temporary immunity to that strain. But your body must develop an immunity to each new strain.

Measles and rubella Among the "childhood diseases" are measles (rubeola virus) and rubella (German measles). Both are caused by RNA viruses and are highly contagious by droplets and physical contact. Measles symptoms include chills, sneezing, runny nose, and redness of eyes followed by a fever, spots on mucous membranes and a rash. Usually the person recovers and is immune. Complications and secondary infections may occur. Rubella is milder and of shorter duration than measles, but can cause serious problems for the unborn child if a pregnant woman contracts the disease. Vaccination programs begun in the 1960s have greatly reduced the occurrence of these diseases.

Polio The polio virus in the intestines produces mild symptoms that are often confused with other minor illnesses. Occasionally it enters the blood or lymph system with no effects. But sometimes it enters the central nervous system and causes paralysis (poliomyelitis or infantile paralysis). Although many people are infected with the polio virus, being paralyzed by polio is rare. In the mid-1950s a strain of the polio virus was treated so as to be nonvirulent and given to people as a "live"-virus vaccine. Vaccination is now routine for infants.

Rabies Caused by a single stranded RNA virus, rabies attacks the nervous system of many different warm-blooded animals. Often associated with dogs, it is common in other carnivores as well. The virus normally is found in the saliva of an infected animal and enters the next victim as he is bitten. In the body the virus goes to the spinal cord where it multiplies and destroys the nerve cells. Various symptoms develop as the virus spreads toward the brain. In dogs the virus is found in the saliva in about 9 days, but serious symptoms begin to show only after 12 days and are not really noticeable for another day or so. The animal usually dies about 16 days after becoming infected. If a human is exposed to rabies, the only known cure is to develop an immunity using a vaccine.

It is suggested that, rather than having students memorize this information, it be used as examples for lecture. Students should read the material for their own information. Further research on these diseases by interested students should be encouraged. Information is abundant and easily obtained.

In the 1980s, however, college students comprised over one-third of the reported cases of measles. It appears that students who were not vaccinated or were vaccinated with an old, ineffective vaccine and missed the disease as a child became exposed to measles when other students brought the virus back from their travels.

interferon: inter- (L. INTER, between or among) + -feron (FERIRE, to strike)

Students should be familiar with the viral diseases listed in the box, but they do not need to memorize the list.

Related discussion on pages 570-76.

Once a virus is inside a cell it is virtually impossible to destroy the virus without harming the cell. Since the reproduction rate of virulent viruses is faster than that of the cells they infect, it would seem logical that once a person's cells contracted a virus, the virus would spread until all the cells of that kind were destroyed.

Chemicals called **interferons*** (IN tur FEHR ahnz) are the body's defense against viruses. Interferons are proteins produced by cells that have been attacked by a virus. The interferons released by a virus-invaded cell affect the surrounding cells. These cells are then able to resist viral attack. Since the viruses are not able to spread rapidly once the interferon has been released, the normal body-cleaning processes can often take care of the viruses.

At one time it was hoped that interferons would be a major cure for viral diseases. It was then learned that interferons were only produced in tiny amounts and are highly specific. The interferon produced by a skin cell did not cause nerve cells to resist viruses. Interferons were so specific that those produced by animals were ineffective in humans. Also, since interferons are proteins they are easily digested and cannot be taken as a pill. Injections did not get enough of the needed interferons to the proper cells. Through genetic engineering bacteria are now used to produce large quantities of specific human interferons. Scientists are once again testing the effectiveness of interferons as an antiviral drug.

9B-5 Other Viral Diseases

In Man

- AIDS
- Chicken pox
- Common cold
- Hepatitis, infectious
- Herpes simplex (fever blisters, cold sores)
- Influenza
- Mononucleosis, infectious
- Mumps
- Poliomyelitis (polio)
- Rabies
- Rubella (German measles, "three day measles")
- Rubeola (measles)
- Shingles
- Smallpox
- Warts
- Yellow fever

In Animals

- Cowpox
- Distemper in dogs
- Foot-and-mouth disease
- Fowl leukemia
- Hog cholera
- Rabies
- Sack brood in bees
- Sheep pox

In Plants

- Mosaic diseases in cabbage, cucumbers, potatoes, sugar cane, and tobacco
- "Breaking" diseases as in Rembrandt tulips

Biological Terms

tobacco mosaic virus (TMV)

The Structure and Functions of a Virus

protein coat
bacteriophage
virulence
lytic cycle
latent virus
interferon

Facet

vaccination

Review Questions 9B-3

1. List (a) several viral diseases of man and (b) several viral diseases that both man and certain animals can have.
2. How do interferons help to stop a viral infection?

Thought Questions

1. Often an attack of a viral disease is sudden and extensive. Account for this.
2. Rabies is a viral disease of both man and dogs. Man, however, is not susceptible to viral distemper which affects dogs. Why can certain viral diseases be shared by dogs and man and other viral diseases not be shared?
3. Immunity to cowpox also serves as an immunity to smallpox, but the two are separate diseases. What reasons can you give for one immunity protecting against two diseases?

Answers–Review Questions 9B-3

1. **(a)** Herpes simplex, smallpox, the common cold; **(b)** rabies, cowpox
2. Virus-attacked cells produce interferon which helps to reduce the spread of viruses. Interferon affects cells surrounding the attacked cells, and the virus has a difficult time entering these cells.

Answers–Thought Questions

1. If conditions are ideal in the host cell, multiplication of the virus and the destruction of the host cell may be very rapid. The massive invasion of new virus particles can quickly spread the infection to other cells.
2. Certain viruses require a specific range of environmental conditions for multiplication. Therefore, many viruses multiply only in certain host species.
3. The two types of viruses are very similar structurally and also have similar metabolic requirements. The machinery for immunity to one disease causes immunity to the other as well.

9C–Diseases and Disorders

Anyone who has suffered or has seen someone suffer from a serious disease has wondered why there is such a thing and how it originated. Scripture teaches that there was no disease in the original creation. At the end of the creation week "God saw every thing that he had made, and, behold, it was very good" (Gen. 1:31).

Today, however, "the whole creation groaneth and travaileth in pain together" (Rom. 8:22). What happened to destroy the peace and harmony of God's original creation? The answer is found in Genesis 3–man's sin, the fall, and the curse caused a host of degenerative changes in the biological realm including disorders, diseases, aging, and death.

God could have allowed us to live in a disease-free world today in spite of Adam's sin. But He chose to use such afflictions to accomplish His purposes in the lives of men. Many people have come to a saving knowledge of Christ in times of great physical or mental distress because they had nowhere else to turn. In the life of a Christian a disease or disorder can be the tribulation that "worketh patience" (Rom. 5:3). Paul's "thorn in the flesh" may have been a physical disorder which God gave him to keep him humble in the face of abundant blessings (II Cor. 12:7). Physical affliction can force us to come apart from our normal routine of living and commune with God. It can make us helpless that we might learn to trust Him more fully. Finally, it can teach us how to sympathize with and comfort others who are similarly afflicted (II Cor. 1:4).

God does on occasion use disease as a punishment for sin (I Cor. 11:29-30). But we must be careful not to jump to conclusions in specific cases. God calls some of His choicest servants to endure serious illnesses for reasons which, for the present at least, only He understands. Job's affliction was not a result of sin (Job 1:8). On the contrary, it appears that he was selected for special testing because of his uprightness.

The account of a New Testament miracle of healing provides a general principle. In John 9:2 the disciples asked the Lord, "Who did sin, this man, or his parents; that he was born blind?" His answer was, "Neither hath this man sinned, nor his parents: but that the works of God should be made manifest in him." Diseases and disorders are a part of the curse, but they can be tools in God's hands for the working of His will in our lives (Rom. 8:28).

In Bible times God used diseases both to discipline (Num. 16:49; Josh. 22:17; and II Sam. 24:15) and to avenge His people (Exod. 9:1-11; I Sam. 5:6-12). Occasionally, God used fatal diseases to remove evil rulers from office (Jehoram [II Chron. 21:18-19] and Herod [Acts 12:21-23]). He will send pestilences (some of which appear to be infectious diseases) as a sign of the end time (Matt. 24:7; Luke 21:11), and they will reach unprecedented proportions during the tribulation (Rev. 16:2, 10-11).

Infectious Disease

An **infectious disease** is caused by an organism that invades the body. Such organisms, called **pathogens,** are parasites that grow and reproduce within the body of their **host,** injuring it in the process. Bacteria and viruses are the two most important types of pathogens. Others are protozoans, fungi, and some animals such as worms.

Diseases and History

On numerous occasions, diseases have changed the course of history. In the 5th century B.C., typhus fever forced the Persian army of Xerxes to call off its invasion of Greece. Returning Crusaders brought the *bubonic plague (Black Death)* from the Near East to Europe, and in the 1300s, 25% of the population of Europe died from this disease. *Typhus* and *dysentery* played as large a role as the adverse weather and the Russian army in Napoleon's defeat in 1812. Even in the 20th century, disease has determined who would be battlefield victors; again it was typhus fever that became a decisive factor in the Serbian campaign of World War I.

People once believed that sickness was a punishment for sin. This is sometimes true, but not always. Emphasize that it is not possible to know how the Lord is dealing with someone else. Few people today would look at someone with pneunomia and believe the disease was a result of sin in his life. Many Christians, however, look at people with ulcers or AIDS and claim these people must be sinners because God has visited them with such judgments. Ulcers can have causes other than "the sin of not trusting God," and AIDS can be contracted in ways other than homosexual contact (ulcers, see pp. 547, 617; AIDS, see p. 571).

From 1603 to 1655, the bubonic plague killed 150,000 people in London alone. From 1894 to 1914, it killed 10 million people in India.

Visual 9C-1 can be used to teach Koch's procedures and to reinforce an understanding of the germ theory of disease. See page T36.

9C–Diseases and Disorders

Notes–Chapter 9C

Student interest generally increases in the unit on diseases and disorders. Sometimes, however, interest lags because of what appears to the students to be outdated material. The diseases discussed are not ones that they or their friends have had. To them, anthrax, typhoid, and diphtheria are merely words, not something someone suffers from.

Sanitary precautions, proper food handling and storage, medical treatment, and various other practices have greatly reduced the occurrence and threat of many of them, but they have not eliminated the disease. All that is necessary for these diseases to spread once again is a failure to apply current scientific knowledge. An understanding of the reasons for various procedures and the consequences of not doing as one should is one of the primary thrusts of this chapter. Many of the diseases that have been in the news media (including AIDS, discussed in Chapter 21B) follow the same basic principles that are outlined for diseases in this chapter.

The latter part of this chapter deals with disorders, such as cancer and tumors. It is important to distinguish between contagious diseases and the various types of disorders. Because one may go to the hospital for either, and a get-well card is usually appropriate for both, many people confuse diseases with disorders. They are not the same. The precautions taken to avoid getting the flu are not the same ones taken to avoid a broken leg. And to treat someone who has the flu with the same methods as one who has a tumor is often not appropriate.

This chapter contains a lengthy list of diseases on pages 250-51. Often students find themselves ignorant of a disease that is being discussed. This list is for their benefit. It is not recommended that students memorize the list. Select a few diseases

exotoxin: exo- (out) + -toxin (L. TOXICUM, poison)

endotoxins: endo- (within) + -toxins (poisons).

inflammation: (L. INFLAMMARE, to inflame)

contagious: con- (with or together) + -tagious (L. TANGERE, to touch)

Diseases in italics are discussed elsewhere in the text (see chart, pp. 250-51).

Inflammation is illustrated on page 249.

The information in this box is significant to the understanding of the chapter and should be covered by all students.

The terms **endotoxin, exotoxin, preformed toxin,** and **food poisoning** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Visual 9C-2 can be used to present how diseases are spread. The "Special Conditions" section can be omitted at this time and presented in conjunction with the material regarding sexually transmitted diseases in Chapter 24B. It is also acceptable to present all of the visual now, but indicate that the material on sexually transmitted diseases will be discussed at a later time. If presenting the material now, consider reading the Teacher Edition materials for Chapter 24.

This chapter will deal primarily with the moneran pathogens. Others are discussed in later chapters.

How pathogens cause disease

How can a tiny microbe bring so much distress to a 150-lb. human? During the **incubation period** of the disease, a few microbes multiply into millions of organisms. The incubation period is the time between *contracting* (being exposed to) the disease and the appearance of the first symptoms. Once the pathogens have multiplied sufficiently, they can affect their host in two ways:

- *Tissue destruction* Pathogens obtain their nutrition from the host's body, which often amounts to destroying host cells, taking them apart both mechanically and chemically and ingesting their remains for food. For example, *typhoid* bacteria destroy portions of the intestine wall and *tuberculosis* bacteria destroy lung tissue. Viruses divert the cell's metabolic machinery from its own functions and in time destroy the cell.
- *Toxin formation* Many bacteria and other microorganisms have the ability to produce poisonous substances called **toxins.** Toxins can cause a malfunctioning of the cells, which in turn produces the symptoms of the disease. In many cases these toxins so disrupt the metabolism of the host's cells that they kill large numbers of cells.

Toxins from pathogenic organisms produce **inflammation*** in surrounding tissues. Inflammation is a condition characterized by increased flow of blood (often causing a reddish appearance), heat, pain, swelling, and occasional loss of function. Some sore throats are an inflammation of the epithelial lining of the throat caused by bacterial toxins. A toxin produced in one area can be carried by the blood to other parts of the body as in *tetanus*, *diphtheria* and *rheumatic fever*.

Kinds of Toxins

There are two basic types of toxins:

- **Exotoxins** Toxins that diffuse from the living pathogenic cell into the surrounding tissue are called **exotoxins,*** or **soluble toxins.** Exotoxins are products secreted by the pathogen. The toxins formed by the *tetanus, diphtheria,* and *rheumatic fever* bacteria are examples of exotoxins. Exotoxins cause the symptoms of most infectious diseases.
- **Endotoxins** Toxins that remain in the pathogen as part of its structure are **endotoxins.*** Endotoxins become a problem to the host as the pathogen dies and disintegrates. Endotoxins can produce violent reactions in tissues around a dying pathogen if they are present in sufficient quantities. Some diseases caused by endotoxins are *bacterial dysentery, bubonic plague,* and *typhoid fever.*

Toxins that are formed by pathogens before they enter the body are called **preformed toxins.** Preformed toxins are often exotoxins. Some kinds of **food poisoning** are the result of preformed toxins released by bacteria that live on the food before it is eaten.

Communicable diseases

A disease that can spread from one person to another by either direct or indirect means is called a **communicable disease.** Most of the so-called childhood diseases such as *chicken pox, measles, German measles, mumps,* and *whooping cough* are communicable diseases which are highly contagious. A highly *contagious disease* is one that is easily spread to others.

The contagiousness of a disease often varies with the stage of development of the disease in the patient. Although a person may be suffering the *symptoms* (effects) of a disease, he may be past the *contagious* stage* and therefore incapable of infecting someone else. In many such cases, the pathogen is either no longer alive or no longer reproducing, but the effects of the damage the pathogen did are still evident in the host.

Some communicable diseases are so contagious that health authorities advise placing the patient in isolation. A person with meningitis, tuberculosis, scarlet fever, diptheria, typhoid fever, and certain kinds of dysentery are often isolated from other people. At times people with some communicable diseases were placed in *quarantine*, a strict isolation often enforced by law.

How diseases are spread

One way of distinguishing between types of infections is by examining the various ways path-

Objectives–Chapter 9C

- List several reasons that God may permit a disease or disorder in a person's life.
- Describe the germ (pathogen) theory of disease. Contrast the germ theory to some historical theories of the cause of disease.
- List and describe the methods by which pathogens are spread.
- List the structural, cellular, and chemical defenses of the human body against disease and explain how they affect the pathogen.
- Discuss the contributions of Alexander Fleming to current methods of disease control.
- Describe the action and limitations of chemotherapy drugs and antibiotics.
- Describe the difference between diseases and disorders.
- List and give examples of the three major kinds of disorders.
- Explain the difference between a benign and a malignant tumor.
- Describe cancer and discuss the theories of the causes of cancer.
- List several cancer treatments and discuss the theory behind each.
- *Discuss the aging process.
- *Define *death*. Differentiate between physical and spiritual death.
- *List several human diseases. Describe their causes, symptoms, and methods of transmission.

*From a Facet.

ogens can enter the body. Knowing these ways should help you observe certain simple precautions to safeguard good health.

❑ **Droplet infections** Many diseases are transmitted by pathogens suspended in water droplets that humans cough or sneeze into the air. Airborne infections generally affect the respiratory tract, though some of them affect other parts of the body as well. *Tuberculosis* and *diphtheria* can be transmitted in this manner. The spread of these diseases is curtailed by practicing sanitary precautions. An individual with such a disease can easily contaminate anything he touches; therefore, it is wise to avoid direct contact with the person or articles he has touched.

❑ **Contact infections** Some diseases are spread by direct contact with a sore or lesion on the skin or mucous membrane of an infected person. *Scarlet fever*, *colds*, *influenza*, and *measles* can be transmitted by touch.

❑ **Contamination infections** Pathogens that enter the body by way of *contaminated food* or *water* often afflict the digestive system. *Cholera*, *typhoid fever*, and many *dysentery* organisms invade and parasitize the intestines. The intestinal wastes of a person who has one of these diseases

Scientists have succeeded in growing leprosy bacteria in a species of monkey. This has not helped to prove that *M. leprae* causes leprosy but has been a useful tool for research on treatments and possible cures of the disease.

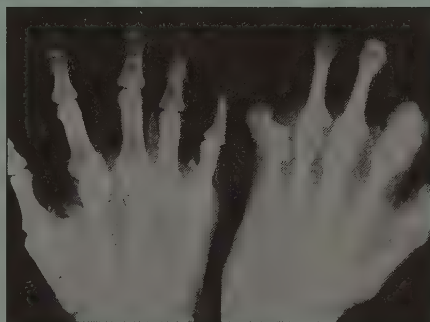
Leprosy

In ancient civilizations leprosy was a dreaded contagious disease. It started with minor white patches of skin and a numbness of the fingers and toes. It caused a progressive disfigurement and so weakened the body that other diseases would infect the person. In time the person died, not always of leprosy, but often of leprosy-related infections.

God told the Hebrews to have lepers live in quarantine "outside the camp" (Lev. 13:46), and if a leper came into a city, the Law required him to cry "unclean" so that others could avoid him (Lev. 13:45).

The disease we call leprosy today *(Mycobacterium leprae)* does not completely correspond to all the descriptions of leprosy given in Leviticus 13 and 14 and similar passages. The disease we call leprosy causes lumpy, discolored patches in the skin that become insensitive to cold, touch, and pain. In advanced cases the patient, if not treated, develops a numbness of the hands, feet, and face. The muscles weaken, and the body becomes disfigured. Because of the numbness, the person can suffer cuts, burns, and even amputation without being aware of it.

In most civilized countries leprosy is rare. Under normal conditions the leprosy bacterium is an obligate parasite of humans and is passed only through direct contact with an infectious leper. Once the disease is diagnosed, it can be treated and stopped before major damage occurs. The person is no longer infectious following treatment. Some lepers, however, continue drug treatments throughout their lives.



Deformity caused by leprosy. Although there is no known cure for leprosy, it can be controlled.

Today many countries do not require lepers to live in a *leprosarium* (special camp for lepers). Before modern drugs, however, leprosy was dreaded, and quarantine was the only method of controlling its spread.

Most Bible scholars agree that when the Bible describes "leprosy," it is speaking of leprosy, several other skin diseases, some molds, and other fungi of cloth, animals hides, and masonry (walls). The spread of a good number of highly contagious diseases (between which people in Old Testament times had no way to distinguish) was prevented by the laws given in Leviticus. Often in the Bible leprosy represents sin since leprosy comes upon the body, spreads, and severely cripples, just as sin affects our spiritual natures.

This box should be read by the students, but spend little time on it in class. There are no terms in the box which are listed in the Biological Terms section at the end of the chapter.

Rather than discuss leprosy by itself, use it as a devotional illustration or in conjunction with other diseases in a class discussion.

An aspect of leprosy that some people find confusing is that Scripture seems to indicate that people could be spontaneously cured of leprosy. Why else would God permit the priests to pronounce a person "clean" after he had been pronounced "unclean" because of leprosy? Human diagnosis by sight alone can easily confuse white skin patches and other symptoms caused by different pathogens with those caused by leprosy. When the symptoms went away, the person could be called "clean." There have been no documented spontaneous cures. There are, of course, miraculous healings of leprosy recorded in Scripture.

they should know. Consider telling the students that they are expected to know for the test those diseases discussed in class. Then carefully select examples of diseases to give in class. It is suggested that the students read the chart, but after they have read it, tell them that they are not responsible for it on the test.

Facet–Chapter 9C

Consider having the students read the Facet that deals with aging and death and merely summarizing the content for them. Another profitable way of covering this material would be to have a class discussion dealing with the topic. A major discussion on death may be more profitable when dealing with euthanasia (see Chapter 24B).

vector: (L. VEHERE, to carry)

Tell students they need to know only the diseases discussed in class, and then choose examples carefully.

Carefully present these disease-spreading processes, and note the importance of sanitary precautions such as hand washing, proper disposal of wastes, and clean living quarters.

Research regarding Mary Mallon can easily be done by students and can be a profitable exercise.

are highly infectious. Good sanitary procedures minimize spreading or getting these diseases. The disposal of body wastes prescribed in the Old Testament helped (at least in part) to help maintain sanitary conditions (Deut. 23:12-13). *Tuberculosis* and *undulant fever* can also enter the body through contaminated food.

❑ **Wound infections** Some pathogens enter the body through wounds. Even small cuts can be serious if they are not properly treated. *Staphylococcus* bacteria are among the most common pathogens of wound infections. *Streptococcus* infections are less frequent but more serious, for they are more likely to enter the bloodstream and spread to other parts of the body. Fortunately streptococcus blood poisoning responds readily to antibiotics. *Tetanus* (lockjaw) and *gas gangrene* are serious wound infections.

❑ **Vector-carried infections** Insects or other arthropods that carry pathogens to other host organisms are vectors.* This can be accomplished in two ways: *mechanically*, as with food contamination by pathogens carried on the bodies of flies

9C-1 *The* Anopheles *mosquito is the vector for the malaria parasite.*

9C-2 *The deer tick is the vector for Lyme disease.*

or roaches, or by the *bites* of such organisms as mosquitoes, flies, and ticks, which inject the pathogen into the bloodstream of the host. *Typhus fever*, *bubonic plague*, and *malaria* are spread by vectors.

❑ **Immune carriers** Diseases are also spread by people (and occasionally animals) who spread pathogens to others without suffering from the disease themselves. Often the carrier has had the disease previously and has developed an immunity to it. Diseases spread in this way include *diphtheria*, *polio*, *scarlet fever*, and *typhoid fever*.

Perhaps the most famous immune carrier in medical history was a cook often called "Typhoid Mary." In the early 1900s a number of cases of typhoid fever near Oyster Bay, New York, were found to involve people who had eaten at the place where Mary Mallon worked. Further study led the investigators to the carrier herself. She had no symptoms of the disease but had infected scores of other people. At least 51 cases of typhoid (and 3 typhoid-related deaths) are attributed to her.

Review Questions 9C-1

1. List several reasons the Lord may have for permitting a person to suffer disease or disorder.
2. Describe the two ways pathogens can affect a host.
3. Compare and contrast exotoxins, endotoxins, and preformed toxins.
4. List and describe six ways a pathogen can enter your body.
5. What causes the disease we call leprosy today? What are the symptoms of leprosy?
6. What are some of the differences between the leprosy described in Leviticus 13 and 14 and the disease we call leprosy today? In the Bible leprosy is often used to represent what spiritual concept? How does this idea parallel the disease?

Answers–Review Questions 9C-1

1. Diseases or disorders in a person's life may result in salvation, patience, humility before God, fellowship with God, trust, and sympathy with, and comfort for, others who are suffering.
2. **(1)** In tissue destruction, pathogens obtain nutrition from the host's body tissues, causing destruction of these tissues. **(2)** In toxin formation, bacteria produce poisonous substances which kill cells of the host's body.
3. Exotoxins, often-secreted waste products of a pathogen, diffuse from living pathogenic cells into surrounding tissues. Endotoxins remain in the pathogen and are released when the pathogen dies. Preformed toxins, usually exotoxins, are formed before they enter the body (e.g., food poisoning).
4. **(1)** Droplet infections travel suspended in water droplets in air and usually affect the respiratory system. **(2)** Contact infections result from contact with a sore or lesion on the skin or mucous membrane of an infected person. **(3)** Contamination infections enter by food or water. **(4)** Wound infections enter through wounds in the body. **(5)** Vector-carried infections are carried by insect or other arthropod bites or food contamination. **(6)** Immune carriers are people who spread disease without suffering the symptoms themselves (e.g., Typhoid Mary).
5. The bacteria *Mycobaterium leprae* is believed to cause leprosy. Symptoms include lumpy, discolored patches of skin that are insensitive to cold, touch, and pain. Numbness, weakness, and disfigurement may also occur.
6. In Scripture leprosy appears to include several other skin conditions. The Bible often uses leprosy as a picture of sin. Leprosy spreads and cripples the body as sin does the spiritual nature.

Defense Against Infectious Disease

God has wonderfully equipped the human body to resist disease. The majority of us enjoy good health most of the time in spite of the fact that we live in an environment filled with pathogenic organisms. Our body's system of defenses is a solid testimony against evolution. These defenses could not have developed over long periods; the entire population would have been killed off by disease at the beginning. The defenses had to work correctly the first time.

The Lord has also permitted man to develop drugs and medical techniques which can help us overcome pathogens which invade our bodies. The first part of this section will deal with the primary body defenses against infectious diseases: *structural*, *cellular*, and *chemical*. Then some of the medical techniques used today will be discussed.

Structural defenses

The **structural defenses,** our "first line of defense" against disease, prevent pathogens from entering the body. The *skin* forms an effective barrier against invading organisms. Moreover, the skin secretes certain fatty acids and salts which are believed to inhibit microorganisms.

The *mucous membranes* lining the respiratory, digestive, urinary, and reproductive tracts are composed of closely packed cells that also form a tight wall against invading organisms. The mucus secreted by these membranes traps microorganisms and other incoming materials such as dust and then disposes of them. The mucous membranes of the nose, trachea, and lungs, for example, have cilia which move the mucus with its trapped materials to the throat. The small amount of mucus continuously coming to the throat is normally swallowed. The digestive juices of the stomach are highly acidic and quickly kill most pathogens that are swallowed.

Certain nonpathogenic microorganisms that live in our intestines (the intestinal flora) are beneficial to us. Physicians do not fully understand how this defense works, but they do know that the intestinal flora occupy the areas that pathogens would occupy if they could. When the normal intestinal flora have been destroyed by medications, pathogenic bacteria can become established and cause disease.

Tear glands, in combination with blinking, not only keep the exposed surfaces of the eye moist and dust-free but also ward off certain pathogens. Tears contain *lysozyme*, a powerful enzyme that attacks the cell walls of bacteria.

Cellular defenses

If microorganisms should get past your first line of defense, your second line of defense comes into action. This consists of phagocytic cells, the lymphatic system, and elevated body temperature (fever).

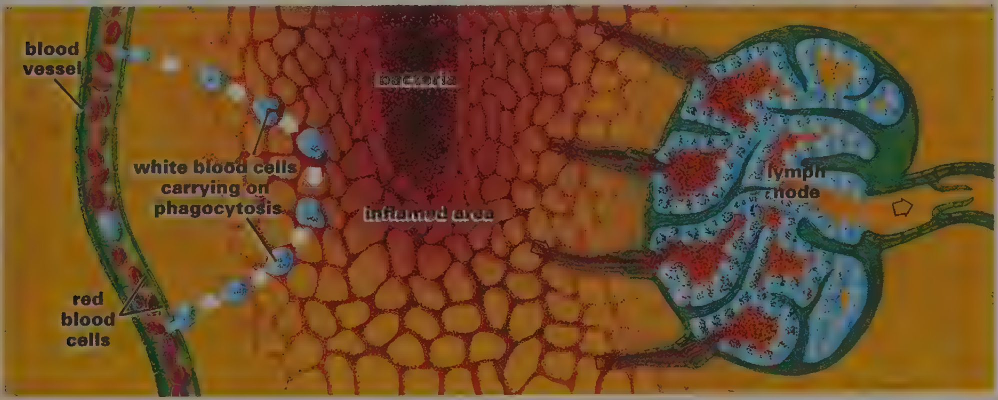
Visual 9C-3 may be used to present the material regarding defenses against diseases. The material concerning general medical care is designed to help review information about infectious diseases. Ask students if they can come up with good reasons for these steps, based on what they know about bacteria, viruses, and how diseases are spread. Ask which diseases these steps may be useful against and which diseases they would not be useful against.

The path of tears across the eye from the tear gland is shown on page 597.

A mucous membrane, with the cilia that move the mucus, is pictured on page 531.

It has been suggested that 1 out of every 100 cells in the body helps to defend the body against diseases.

9C-3 *An infection of bacteria causing inflammation, being attacked by white blood cells and being carried to the lymph nodes*



Be sure to inform the students which, if any, of these diseases they need to memorize. It is suggested that students use this list as a *reference* while reading and learning the principles taught in the main text section. Most of the information here can be easily looked up, and, with few exceptions, is not worth memorizing on the high school level.

Some viral and protozoan diseases are discussed elsewhere. Most of the diseases described here are caused by bacteria.

Cholera outbreaks in the United States in recent years have been associated with improperly cooked seafoods taken from infected waters along the Mid-Atlantic and Southeastern coasts.

Diphtheria vaccination uses a formalin-treated toxin which causes the body to produce antibodies. Testing for diphtherial immunity is done by placing a small amount of the toxin under the skin. If the toxin causes a reaction, the person is not immune to diphtheria. If there is little reaction, the person has the antibodies for the disease. Children receive immunization with the DPT series (D-diptheria, P-pertussis [whooping cough], T-tetanus), which is required for entrance into many schools and countries.

Gangrene refers to tissue death.

Serum hepatitis is also caused by a virus but is contracted through contact with infected bowel products.

Shellfish from polluted waters are a significant source of infectious hepatitis.

Many forms of meningitis that are resistant to antibiotics are known to exist and create problems in hospitals.

Since heat destroys the botulism toxin, canned goods that may have the toxin should be thoroughly cooked before serving. Botulism often occurs in home-canned foods that were prepared with too little heat to kill all the botulism spores.

Human Infectious Diseases

You may not be familiar with all of the diseases mentioned in this chapter or may have some wrong ideas about them. The following gives some information or tells where in this book you can find information about these diseases. Other conditions are discussed in this book and can be located using the index.

AIDS See page 571.

African Sleeping Sickness See page 266.

Botulism is food poisoning caused by a bacterial exotoxin. It is one of the most powerful poisons known. The symptoms generally appear within 12-36 hr. and include fatigue, dizziness, and paralysis of the muscles of the eyes and pharynx. Paralysis spreads to the respiratory system. Botulism is often the result of improperly canned food. If the spores of the botulism bacteria (which can be found in the soil almost everywhere) enter the food and survive canning they can grow anaerobically and produce the toxin.

Bubonic plague is caused by a bacterium which lives in rodents but can be carried to humans by rodent fleas. The symptoms include swelling of the lymph nodes (called *buboes,* which accounts for the name "bubonic plague") and spread through the body. Rodent control is the best prevention. Antibiotics are used in treatment, and the person develops an immunity once he recovers. A virulent form in the Middle Ages caused repeated plagues and killed a quarter of the population of Europe. This form is believed to have caused a breakdown of the blood which turned the person a dark color and accounts for the name "black death."

Colds See page 243.

Cowpox See pages 238-39.

Cholera, one of today's most common infectious diseases, is caused by bacteria and is transmitted by contaminated water. The bacteria live in the human intestine and produce toxins which affect the intestinal wall and its permeability. The person loses excessive water, causing extreme dehydration, then shock. Prevention includes treating water and proper disposal of sewage. Vaccines of dead cholera cells are available, but the immunity is of short duration.

Diptheria is caused by a bacterium that generally lives only in the throat where it produces exotoxins. The toxins cause fever, a tired feeling, and can harm the heart muscles, nerves, and fatty tissues. In the throat the bacteria causes soreness and produces a leathery, bluish-white membrane composed of bacteria, dead cells, and blood-clotting fibers. This membrane can cause death by suffocation. Transmission is by droplets. Treatment involves giving antibodies to destroy the toxins and antibiotics to destroy the bacteria. Vaccination by a toxoid is routine, and diptheria, once a major killer of children, is now rare in most of the civilized world.

Dysentery is a condition of abdominal cramps and diarrhea which involves blood in the stool. It may be caused by certain chemicals, bacteria, protozoans, and worms. Bacterial dysentery is caused by several species. Some species cause mild symptoms, but some species cause high fever, chills, convulsions, and frequent bloody stools resulting in dehydration. A spontaneous cure usually happens within a few days. The bacteria invade the body through tainted food, water or unsanitary practices (also see *amoebic dysentery,* page 266).

Flu See *Influenza,* page 243.

Gas gangrene is caused by bacteria which enter the body through a wound. The bacteria are obligate anaerobes which grow deep in the body and kill tissues. The area often swells and may ooze gaseous and liquid waste products of anaerobic decomposition. The best prevention is to clean dirty wounds thoroughly and to use antibiotics early. Once established, amputation of the infected area is sometimes necessary.

Hepatitis is a general term meaning an infection of the liver (also see *Infectious hepatitis,* page 243).

Impetigo is a bacterial infection of the skin. It causes blisters which release a fluid that dries to form a crust. Transmitted by contact with the fluids from the sore, it is often a problem for infants and small children.

Influenza See page 243.

Leprosy See page 247.

Malaria See pages 265, 267.

Measles See page 243.

Meningitis is any inflammation of the meninges (the membranes covering the brain and spinal cord). Some viruses and several species of bacteria can cause meningitis. The symptoms include headaches, spasms, stiff neck, and exaggerated reflexes. In severe cases, convulsions and death occur. Most forms of bacterial meningitis enter through the mouth and require close

contact to be passed from one person to another. Vaccines are available for some forms.

Polio See page 243.

Rheumatic fever is a reaction to the toxins produced by several species of bacteria. These bacteria infect the throat and cause a fever. The body produces antibodies in reaction to the bacteria, but these antibodies fail to recognize certain tissues as being part of the body and begin to destroy them. Some of these tissues are in the heart, and the antibodies may cause severe heart damage. The symptoms include a sudden fever and joint pain several days to 6 weeks following a streptococcus infection. Little can be done about the antibodies in the blood, but the bacteria can be treated with antibiotics, thus limiting the antibody production.

Salmonellosis is an intestinal disorder caused by several of the members of a bacteria genus. Technically, salmonellosis is not food poisoning because the organism lives in the intestine where it produces toxins which cause headache, chills, vomiting, diarrhea, and fever between 8-48 hr. after being consumed. The symptoms last a few days and are rarely fatal even without the use of antibiotics.

Scarlet fever is a usually quite mild infection caused by *Streptococcus* bacteria. Within 2-7 days of exposure the person experiences a sore throat (where the bacteria generally begin growing) and fever. A body rash develops and in time the skin peels. The face is flushed (hence the name scarlet fever) with a pale ring around the lips. The person also has a coated, inflamed tongue. Complications, including rheumatic fever, sometimes occur. Former patients have partial immunity. Antibiotics are effective in controlling the disease.

Smallpox See pages 238-39

Syphilis See page 644.

Tetanus is also called "lockjaw." The spores of the anaerobic bacteria that cause tetanus are common in topsoil. If they enter a wound they cause damage to the blood supply and then can grow in anaerobic conditions and produce toxins. These toxins affect the central nervous system by causing continual impulses to be sent to the muscles. The muscles contract and remain rigid. The muscles of the jaw are often involved. If not treated the person often dies a painful death as more and more of his muscles are affected. Antibiotics can kill the bacteria, but the toxin must be treated by antitoxin. Temporary immunity can be achieved by injections of a toxoid.

Tuberculosis (TB) is still a dreaded respiratory infection. It may cause little damage in healthy people, but in others, for reasons not completely understood, the bacteria may cause fatigue, weight loss, and a persistent cough as it forms clumps of damaged lung tissue called tubercules. In advanced cases there is bleeding in the lungs as the bacteria destroy lung tissue and the person coughs up blood. The bacteria are spread by inhaling airborne bacteria which may live in the air for hours. Treatment includes rest and antibiotics. It is difficult to completely wipe out the bacteria, and recurrent attacks are common. A species of tuberculosis bacteria was common in cattle and passed to humans in milk. Pasteurization of milk from healthy cows has virtually eradicated this type of tuberculosis in humans in the U.S. and Europe.

Typhus See pages 234-35.

Typhoid is caused by a bacterium which enters the body through contaminated food or water. It starts in the digestive tract but later enters the blood. In time, the bacteria invade the organs. A fever and rose-colored spots on the abdominal skin develop. The fever may remain for weeks. In time, the symptoms go away, but the person may still harbor the organism. Often the bacteria live in the liver and gall bladder, causing the person to pass the bacteria in his feces. A vaccine is available and is recommended for those who go to areas where typhoid is common.

Undulant fever is caused by bacteria which normally enter the body through milk or close association with animals. The symptoms include chills, fatigue, headaches, backaches, and fever which normally goes up and down (undulates) within a 24-hr. period.

Whooping cough (pertussis) is caused by bacteria which a person inhales. After an incubation period of about a week the initial symptoms of a sore throat and minor cough develop. A persistent cough develops after 1 or 2 weeks followed by a long forced inspiration (or "whoop") ending in the expulsion of a clear, sticky mucus. This stage may last 4-6 weeks and often leads to other complications.

Rheumatic fever is most common in children and young adults from 5-15 years old. Once a person has had rheumatic fever, he is susceptible to having it again. The valves of the heart are often affected, causing a permanent weakness of the heart.

In 1985, 18,000 persons in Illinois contracted salmonellosis caused by an antibiotic-resistant strain of *Salmonella typhimurium* that had managed to pass through a faulty valve in a milk-pasteurization plant.

The tuberculin skin test does not tell if a person is suffering from tuberculosis. If he has had the bacterium at some time in the past, even if he lacked noticeable symptoms, the test would be positive. Tuberculosis is less of a problem in most civilized countries today, not because of an effective vaccination or new drug, but because of improved nutritional and socioeconomic conditions. Tuberculosis is still among the top ten diseases reported to the Center for Disease Control in the United States, and in some areas of the world, it is a major killer. The X-ray screening used in the past is not used as much today because the disease is so rare in most civilized countries that the expense and risk are not worth it. Today there is a live vaccine available.

Typhoid responds to certain antibiotics when it is in the intestine but does not respond well to most antibiotics when found in white blood cells or other organs. The few antibiotics that are useful in severe cases can be toxic. Antibiotic therapy must be continued for a long time to wipe out all of the bacteria.

The whooping cough vaccine is usually given as part of the DPT shot. Most cases of whooping cough in the United States are seen in children less than a year old.

antibody: anti- (Gk. ANTI, opposite or against) + -body (Ger. BOT-, container)

antibiotics: anti- (against) + -biotics (life)

In Chapter 21B the immune system, which is directly related to antibodies, is discussed.

White blood cells are discussed and pictured on pages 553 and 556.

These phagocytes ingest almost all forms of foreign substances. They eat inhaled dust which gets into the lungs. Chemicals in cigarette smoke kill the phagocytes. When the phagocytic cells ingest silica and asbestos, they die.

The lymphatic system is discussed on pages 568-69.

The toxins that go into the blood usually cause general fevers, while toxins that remain in a specific area cause localized fevers.

Although chemical agents, derived mainly from plants, were used in ancient times, they were generally administered to treat the symptoms of a disease rather than the pathogens that caused it. The science of chemotherapy did not come into being until the beginning of the twentieth century.

There are two types of *phagocytic cells*–fixed and free. The fixed cells are found in lymph nodes throughout your body and in certain tissues and organs (such as liver). The free phagocytic cells include certain white blood cells (leucocytes).

When an invasion of microorganisms occurs anywhere in the body, phagocytic white blood cells leave the bloodstream through the walls of tiny blood vessels and travel to the site of the infection. There they isolate the invaders from the rest of the body by forming a barrier around the area. At the same time many white blood cells engulf and digest the pathogens with enzymes. In the process toxins kill many of the white blood cells. The bacteria, white blood cells, and fluids that remain after the conflict form **pus.**

The liquid part of the blood plays an important role in our cellular defensive system. Normally fluid from the blood fills the spaces around all of your body cells. But in an area of infection, extra fluid fills the area, causing much of the swelling seen around an infection. This fluid washes many of the pathogens and other substances from the area. The fluid carrying the foreign substances enters the vessels and nodes of the *lymphatic system.* When in the lymphatic system the fluid is called *lymph*. In the lymph nodes *fixed phagocytic cells* help filter the lymph. The lymph then reenters the bloodstream (see pages 568-69). Enzymes break down the materials that remain in the phagocytic cells of the lymph nodes into soluble, nontoxic substances which are eventually carried away by the blood as wastes.

Although most people think of a **fever** (a raised body temperature) only as a symptom of a disease, a fever is a defense reaction to some infections. Some fevers are local (only at the area of the infection), but in more severe infections fevers may involve the whole body. The higher temperature makes the environment less favorable for many parasitic organisms. Even a small increase can appreciably inhibit the growth of many pathogens. Also, chemical reactions proceed more rapidly at higher temperatures, allowing the body not only to accelerate its defenses but also to use defenses that would not normally be put into operation. However, if the body temperature goes too high or is raised for too long, damage to some body tissues (especially the brain) may result. In such cases a physician often prescribes measures to decrease the body temperature.

Chemical defenses

Our third line of defense against disease is made up of chemicals called **antibodies.*** Antibodies are protein molecules made by the body and carried by the blood, which are able to combat specific pathogens or their toxins. Antibodies are specific, attacking only certain substances. (Antibodies are further discussed in Chapter 21B.)

Medical control of disease

If the body's defenses should not be able to combat the pathogen, or if the physician feels it would be wise to help the body, there are several "chemical warfare" tools available. One of these is **chemotherapy,** the use of chemical agents to treat or prevent disease. Physicians select chemicals that will injure or kill specific pathogens without damaging the host's body. There may be *side effects* (symptoms caused by the chemicals). If side effects are minor, patients must tolerate them during the period of treatment.

Today the most used form of chemotherapy for infectious diseases involves **antibiotics.*** These are chemicals produced by living things which are either *bactericidal* (killing bacteria) or *bacteriostatic* (inhibiting growth of bacteria). To be useful an antibiotic must have little effect on tissues of most humans. The properties of antibiotics were discovered by accident in 1929 by the British bacteriologist Alexander Fleming. Fleming, returning to his laboratory after a short vacation, noticed a blue mold growing on a Petri dish culture that had become full of bacteria. Around the mold there was a clear, circular area where the bacteria had been killed. The mold had produced a toxic substance that had diffused outward, killing the bacteria.

Fleming identified the mold as a species of *Penicillium* and named the substance it produced **penicillin.** Realizing the potential of this substance as a drug, he tested it, found that it was *not* toxic to most laboratory animals, and determined that it was effective against many different

Early Chemotherapy

Early chemotherapy is an interesting point to discuss in class. Paul Ehrlich, a German chemist and bacteriologist, noted that certain bacteria selectively took up specific dyes when stained for microscopic viewing. He realized that the staining procedure damaged the bacteria, and he reasoned that it should be possible to treat disease by administering the right dye, one so specific that it would not injure the host. Ehrlich's first success came with the discovery of *trypan red*, a dye that attacks the pathogens that cause African sleeping sickness.

Several years later he discovered *Salvarsan*, an arsenic-containing chemical that is effective against the *syphilis* spirochete. In 1912 Salvarsan was superseded by a still better drug, *Neosalvarsan,* which was easier to produce. It remained the standard treatment for syphilis until it was supplanted by antibiotics in the 1940s.

Gerhard Domagk, a German chemist, experimented with the effects of certain *sulfa drugs* on microorganisms. In 1935 he reported that of the more than 1,000 nitrogen-containing dyes he had tested, one of them cured streptococcal infections in mice and, it was later discovered, in humans. Later Domagk discovered that only a part of the chemical was actually active against bacteria–the part called *sulfanilamide*. Sulfanilamide, the first of an important family of compounds called the *sulfa drugs,* is *bacteriostatic* (preventing the multiplication of bacteria). Only a few of the thousands of potential sulfa drugs are both effective against bacteria and low in toxicity. Even those that are generally considered acceptable may produce toxic or allergic reactions in some people. Sulfa drugs are useful in the treatment of intestinal, respiratory, and urinary infections but are used only when other, less harmful methods of treatment cannot be used.

9C-4 *Although Fleming discovered penicillin in 1929, significant use of the drug did not happen until 1940. Then, under the pressure of World War II, pharmaceutical companies mass-produced it, bringing the price to 1/1000th of its original cost.*

kinds of bacteria. By 1942, scientists had produced a pure penicillin–a yellow powder having a remarkable potency which they used successfully against many bacterial infections.

In 1943 *streptomycin,* an antibiotic produced by the soil organism *Streptomyces griseus,* was discovered. This antibiotic is effective against tuberculosis and several other diseases that do not respond to penicillin. However, it produces various side effects in humans. Because more effective, less toxic medicines are available, streptomycin is rarely used today.

9C-5 *In order to identify bacteria and test their sensitivity to antibiotics, medical laboratories prepare plates such as this one. The right compartments have different media. Which media support growth of the bacteria and what the colonies look like help to identify the bacteria. The paper discs on the left contain different antibiotics. The ring around each disc tells the effectiveness of that antibiotic against the bacteria.*

Because antibiotics affect many pathogenic bacteria, some people are tempted to use them without proper medical prescription. But such use can cause long-term or short-term damage to their health. The decisions about whether to use an antibiotic, how much to use, and how long to use it should always be made by a physician.

Since many antibiotics are rapidly removed from the body (usually in the urine), a physician often prescribes a series of doses to be sure the pathogen is completely under control. A pathogen that is only partly "wiped out" can often make a comeback if repeated doses are not taken.

The quest for new antibiotics continues. Some infectious diseases are not yet under control. Then, too, in any population of microorganisms a few may be *naturally resistant* to an antibiotic. Although the nonresistant strains may be killed off by the antibiotic, the naturally resistant ones survive and multiply. As time goes on the resistant organisms form a greater percentage of the total population of that pathogen. This makes it increasingly difficult to treat the disease with the same antibiotic. Since a pathogen resistant to one antibiotic is often affected by another one, scientists are eager to increase the number of antibiotics available.

Occasionally you hear that a pathogen has "developed" a resistance, implying that the pathogen is evolving. This "development" of resistant strains is usually an example of selection from an already-existing gene pool, not the development of new characteristics. Even if a pathogen did become resistant to an antibiotic because of mutation, this is not evolution, but merely a variation of an existing organism.

Review Questions 9C-2

1. What are the body's three lines of defense against disease?
2. List and describe several of the body's structural defenses against disease.
3. Describe the working of the body's cellular defenses against disease.
4. What method can physicians use to help control a pathogen that is in the body?
5. What is the difference between bactericidal and bacteriostatic chemicals?

Answers–Review Questions 9C-2

1. (1) Structural; (2) cellular; (3) chemical
2. (1) Mucous membranes trap microorganisms and dispose of them. (2) Intestinal flora occupy an area that could otherwise be occupied by pathogens. (3) Tear glands produce lysozymes. (4) The skin is a physical barrier.
3. (1) Phagocytic cells, located in the lymph nodes, liver, and blood, engulf and destroy foreign organisms. (2) Lymph washes pathogens from the area of infection. Foreign substances are transported through lymph vessels to nodes where they are filtered out by fixed phagocytic cells. (3) Fever inhibits the spread or growth of pathogens, and the higher temperature increases the metabolism of body cells that fight the infection.
4. Antibodies attack antigens and render them harmless. They can neutralize toxins, destroy membranes or walls of antigens, clump antigens to help phagocytize them, or neutralize viruses by destroying their protein coats or preventing their entrance into cells.
5. Bactericidal chemicals (antibodies, penicillin, streptomycin) kill bacteria; bacteriostatic chemicals (sulfa drugs, Salvarsan) prevent multiplication of bacteria.

benign: beni- (L. BENE, good) + -gn (L. GENUS, birth)

biopsy: bi- (life) + -opsy (Gk. OPSIS, a sight)

malignant: (L. MALUS, bad) + -gnant (birth)

Disorders

For our study, we will define **disorders** as afflictions which are not caused by a pathogen. Disorders can be grouped into three major types:

- **Inherited disorders** These disorders are either the direct result of an inherited gene (as in hemophilia, PKU, or sickle-cell anemia) or an inherited tendency for a disorder (as may be the case for diabetes mellitus).
- **Injuries** Caused by physical damage to the body, injuries may be temporary (as a bruise or minor cut), or permanent (as the loss of a leg or eye). Burns, broken bones, sprained joints, concussions (impaired activity of the brain caused by a severe jar or shock), and some hearing and vision defects are the results of injuries.
- **Organic disorders** These conditions are not inherited or caused by injury. A *deficiency disease* results from improper nourishment such as the lack of a vitamin or mineral. *Chemical poisoning* and *radiation sickness* result from exposure to environmental factors. Strokes, ulcers, blood clots in the vessels (thrombosis), types of hardening of the arteries, kidney stones, gallstones, and many nervous disorders are caused by unknown or only partially understood factors.

Deficiency diseases, see pages 545-46.

The rest of this chapter includes a discussion on two organic disorders: benign tumors and cancer.

Benign tumors

Occasionally a group of cells stops functioning normally and grows a structure different from the tissue of which it is a part. This abnormal growth of cells is called a **tumor.** If the growth is slow and localized, it is called a **benign*** (bih NINE) tumor. The body often walls off areas of benign tumors, preventing their spread.

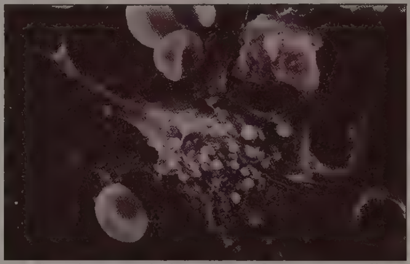
Cancer is sometimes described as cells that are too much alive. Rather than slowing down as they become crowded–*contact inhibition*–they seem to continue to grow as rapidly as healthy, uncrowded cells.

Some examples of benign tumors are common (brown) moles and certain birthmarks. The tumor cells often closely resemble those of the tissue from which they originated. Some benign tumors grow to a certain size and stop; others expand slowly, exerting pressure on the surrounding tissues. In some cases the pressure from a benign tumor can seriously impair the functions of an organ. For example, it may obstruct a secretion, cut off the blood supply to a region, or, as in the case of a brain tumor, cause serious disability or death. Benign tumors of the hormone glands can cause the gland to secrete either too much or too little of its hormones.

The cause of most benign tumors is not known. Surgical removal is a successful and lasting treatment in a vast majority of cases.

Is It Cancer?

Both benign and malignant tumors may occur anywhere in the body. To diagnose which type of tumor is present, a doctor performs a **biopsy.*** In a biopsy a sample of tissue from the tumor is removed and sent to a **pathologist** (puh THAHL uh jist), a specialist in diseased tissues. The specimen is analyzed microscopically to determine if it is benign or malignant.



The characteristic spikes of a cancer cell

Cancer

If the growth of a tumor is rapid and chaotic it is called a **malignant* tumor.** A malignant tumor is often called a **cancer.** The nuclei in the cancer cells are larger and often contain more DNA, and cell growth and reproduction are more rapid than in normal tissue or benign tumors. The cells in a malignant tumor often develop a bizarre appearance and may even have an abnormal number of chromosomes. Cells that become cancerous stop their normal functions and become harmful to the body. Cancer cells may separate and travel to other parts of the body, starting new tumors.

Cancer cells are cells of the body that have changed. Cancer researchers point to a two-step process in developing a cancer: *initiation* and then

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. The Facet presents the physical and spiritual concerns regarding physical aging and death.

The terms **gerontology** and **clinically dead** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Aging and Death

In addition to diseases and disorders, humans face the problems of aging and the prospect of death. Scripture indicates that aging and death are both a part of the curse that God pronounced in Genesis 3. *Aging* is the continual degeneration (wearing out) of our bodies. Stooped posture, thinning and graying hair, and wrinkling and drying skin are but some of the outward signs of the deterioration that is taking place throughout the body. Organs gradually wear out; the heart and blood vessels become less elastic; bones become more brittle; joints stiffen; brain cells die and are not replaced; the eyes become less capable of focusing; dental problems make eating difficult; injuries heal more slowly; and the resistance to disease diminishes.

Aging

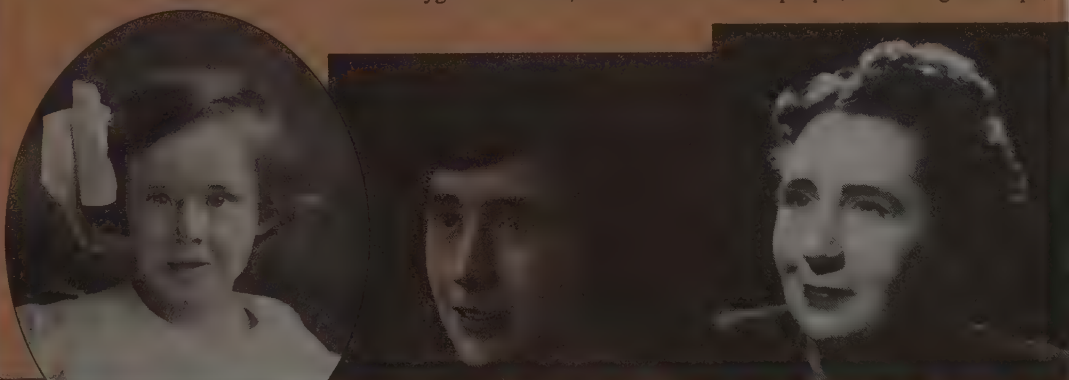
Much research is being conducted in the field of **gerontology** (JEHR un TAHL uh jee), the science of aging. Researchers have determined that degeneration begins when a person is in his 20s, shortly after his growth has been completed. Scientists still do not agree about the physical causes of aging. One theory holds that it is the cumulative effect of wear and tear, the "battle scars" of the continual fight against disease, injury, and the rigors of life itself.

Aging has also been attributed to waste accumulation in the cells. Wastes are continually being removed from cells, but some types of wastes are not completely removed. Therefore, as cells grow older, the concentration of certain wastes increases, and presumably the function of the cell is being impaired. Although a waste product called *lipofuscin* (LIH poh FUS in) accumulates in older nerve cells, no one has demonstrated that this causes a loss of function.

Another theory is that aging and death are genetically programmed into the body. From the moment the zygote is formed, the individual follows a prescribed program through the different stages of life: embryo, infancy, childhood, adolescence, young adulthood, middle age, old age, and death. Thus, aging and death are a natural part of the life cycle, directed by genetic machinery. Some gerontologists believe there are genes that trigger degenerative processes as life progresses. Research has shown that certain human cells have only about 100 generations built into them. After their appointed number of cell divisions they degenerate and eventually die.

There also seem to be complex aging mechanisms through which one part of the body can transmit aging instructions to another part.

Christians view aging as a divinely ordained modification of our physical being that came about after the Fall. We should be willing to accept aging, knowing that ultimately we will receive a glorified body that is incorruptible (unaging) (I Cor. 15:51-57). Unregenerate people, not having this hope,



Life-After-Death Experiences

Life-after-death experiences are interesting to discuss in class. Several years ago a study was made on people who had been pronounced dead and then revived. Some of these people reported that they had traveled to a place of beauty and had experienced a sense of well-being. Many of these believed they had actually been to heaven in the presence of the Lord Himself, who allowed them to return to earth because their work was not finished.

At first some people believed that these encounters were proof that everyone goes to heaven when they die. But later, it was reported that many such people have had extremely unpleasant experiences. The memories were so distasteful that the people had suppressed them (as with nightmares) or were reluctant to talk about them. The first study has now been somewhat discredited because of its incompleteness; a scientific study in which a significant amount of data is ignored is actually *un*scientific. One often-cited, positive example involves a well-known evangelist. After a restless night on December 22, 1899, Dwight L. Moody said, "Earth recedes; heaven opens for me." His son, thinking Moody was dreaming, tried to awaken him. "No, this is no dream. . . . It is beautiful. . . . If this is death, it is sweet. There is no valley here. God is calling me, and I must go. . . . This is my triumph; this is my Coronation day!" He entered a state of unconsciousness, and his physician gave him stimulants. After a few moments, he regained full consciousness and said, "This is a strange thing. I have been beyond the gates of death and to the very portals of

electroencephalogram: electro- (electricity) + en- (in) + -cephalo- (Gk. KEPHALE, head) + -gram (GRAMME, letter)

Also see *Beyond Death's Door* by Maurice Rollins (Nashville, Tenn.: Thomas Nelson, Inc., 1978).

See the material on the sanctity of human life, abortion, and euthanasia (pp. 639-43).

Point out to students that although life-after-death experiences may be interesting, they are not a significant study. The Word of God tells Christians all they need to know in this life regarding the next. Scientific experimentation with spiritual matters is not possible nor profitable. It also invites spiritual intervention by Satanic powers–something Scripture warns against.

would like to find some way to block the sequence of aging and thus "beat the system." Perhaps someday man will be able to "push off" the effects of aging, extending useful life. Scientifically, this seems a long way off, but the Bible does not say that man cannot do it.

Death

Someone made a statement once that the surest way to live to a ripe old age is to choose ancestors who lived to ripe old ages. This statement contains a basic element of truth: genes do set limits upon a person's life. But within these limits there is considerable room for individual variation. In addition to having "good genes," one must avoid accidents and diseases and practice good living habits (proper diet, rest, exercise, and a lifestyle conducive to good mental and emotional health).

Yet, barring the Lord's return for His saints, death is inevitable for every person. Most Christians believe that scientists will never find a way to avoid death. Death appears to be a part of the universal degenerative trend and is in keeping with the Scripture, which says "it is appointed unto man once to die" (Heb. 9:27). It appears that only God Himself could change this plan.

What exactly is death? In former times men relied on two main indicators–absence of heartbeat and absence of breathing. But the cells of the body do not die immediately when these functions cease. Victims of drowning and electrical shock can often be successfully revived if action is taken quickly. Even brain cells, the most fragile type of cells, can live for a couple of minutes after their blood supply is cut off. A person resuscitated within this time would suffer little, if any, permanent damage. If the body temperature is lowered (as may happen when a person drowns in cold water), he may be revived after half an hour or longer without brain damage.

Therefore, a definition of death which is based only on heartbeat and breathing is unsatisfactory. Now scientists usually consider the brain the indicator of the state of the physical organism. A functioning brain produces minute electrical impulses called *brain waves*. An *electroencephalogram** (ih LEK troh en SEF uh luh GRAM) or EEG measures these waves. If there is no electrical activity in the brain, the EEG is "flat." Medical authorities tell us that if there are no brain waves for 24-48 hr., there is no hope for the patient. A person in this condition is **clinically dead.**

Suppose that the heart of a clinically dead person is still beating and that the person is still breathing (without the aid of any supporting equipment). Would it be proper to bury such a person? Even though the brain may be "dead," it would seem strange indeed to bury a body that was still breathing. To avoid such a dilemma, many authorities insist that all three criteria exist before burial. Problems often arise when "life-support" equipment is being used to maintain the heartbeat or breathing while there is little or no brain activity.

The Christian recognizes death to be the departure of the soul and spirit from the body. For the Christian, to be absent from the body is to be present with the Lord (II Cor. 5:8). Medical instruments cannot measure the nonphysical parts of the body to determine when it has degenerated too far to be inhabitable by the soul and spirit. However, we must be careful: God does work miracles!

Most Christians doubt that man will ever be able to conquer physical death through scientific endeavors. Biological problems are numerous, and Scripture tells us that the power of life and death is in the Lord's hands (Matt. 28:18). Although man may not be able to conquer death, there is One who promises us the victory over it. Christ's death on the cross conquered physical death; He rose from the grave having a new, incorruptible (unaging), glorified body.

The just eternal fate of every sinful human being is hell, a place that God prepared for Satan and his hosts. However, Christ also conquered spiritual death so that those who believe on His name would live eternally with Him in their glorified bodies. With these promises in the Word of God, it is easy for the Christian to say, "O death, where is thy sting? O grave, where is thy victory?" (I Cor. 15:55).

Review questions on page 258.

heaven, and here I am back again." As the doctor sought to administer more drugs, Moody questioned the wisdom of doing so; he was ready to meet his God. Shortly thereafter, he passed away. (Quoted material taken from W. R. Moody's *The Life of Dwight L. Moody* [Kilmarnock, Scotland: John Ritchie, Ltd.], pp. 473-75.)

Actually any such study of life after death is unscientific because it is not observable nor is it repeatable, and both are necessary parts of a scientific study.

promotion. Initiation is generally accomplished in one of three ways.

□ **Carcinogenic chemicals** Cancer-causing chemicals are called carcinogens. The best-known carcinogens are in the chemical residue from smoking or use of other tobacco products. A definite link between smoking and lung cancer has been established for many years. Other carcinogenic chemicals include formaldehyde, asbestos, and xylene.

□ **Radiation** Skin cancer can be caused by excessive exposure to the ultraviolet rays in sunlight. Fortunately, skin cancers (if diagnosed soon enough) are usually mild and often can be removed in a doctor's office. X-rays are also regarded as a cancer hazard. Both skin cancer and leukemia (cancer involving white blood cells) have been linked to X-rays. Highly radioactive substances are considered to be cancer-producing agents. Small amounts of radiation (minor exposure to the sun or medical X-rays) are not believed to be harmful.

□ **Viruses** In humans some cancers apparently are caused by viruses. It is likely that many cancers are not virus related.

Once the cell is "potentially cancerous" it must be affected by environmental factors to convert into a cancerous tumor. These tumors can be promoted by diet, general health, and various other things depending on the kind of cancer and the person's genetic make-up.

Almost any tissue in the body can develop a cancer, but each tissue can get different kinds of cancer, and some tissues can develop several different cancers. What a person does to prevent one form of cancer may have no effect on another form. For example, there are several kinds of skin cancer, and they are not all caused by the same factors.

Who gets what kinds of cancer also depends a great deal on their genetic make-up. Certain cells in some people are naturally resistant to some forms of cancer. These people would rarely get that form of cancer. The next person, however, may have inherited a weaker cell, and he develops that form of cancer even if he is careful to avoid what is believed to initiate or promote that cancer.

It is, of course, wise to avoid those things that are known to induce or promote cancers, but one must also be careful not to be caught up in every "new fad" or advertising gimmick designed to cash in on people's natural fear of cancer.

Cancer treatments

The leading method of treatment for cancer is surgical removal of the affected tissues. Many lives have been saved in this way; however, the surgeon is completely successful only if he is able to remove all the cancerous cells. Thus, it is important to diagnose cancer early, while the affected area is still small. If the disorder has spread to the lymph nodes or to vital organs, the chances for survival are reduced. Even if it is impossible to remove all the cancer, surgery may still help relieve pain, restore lost bodily functions, and slow the spread of the disease.

Some people are very prone to skin cancer and even if they avoid exposure to the sun, they develop cancerous patches. Other people's skin is quite resistant to skin cancer, and they can tolerate moderate exposure to the sun without problems. Even these people, however, can develop skin problems (including cancer) from overexposure to the sun.

Another treatment for certain cancers is *radiation*. Physicians use X-rays or emissions from radioactive isotopes to destroy cancer cells, and, they hope, to leave most normal cells intact. This method can sometimes completely eradicate localized cancers. In more widespread malignancies radiation therapy may provide relief from pain and prolong the life of the patient, but complete recovery is rare. Radiation, however, can *cause* tumors and other undesirable side effects.

9C-6 *A person being prepared for radiation treatment*

Physicians sometimes treat cancer by *chemotherapy*. In this case the chemical is directed not at an invading pathogen but at cancer cells. Often the chemical chosen interferes with cell division.

Chemotherapy for cancer often involves the use of poisons.

Answers–Review Questions 9C-3 *(p. 258)*

1. **(1)** Inherited disorders are the results of inherited genes or tendencies for a disorder (e.g., PKU, sickle cell anemia, hemophilia). **(2)** Injuries include any physical damage and may be temporary or permanent (e.g., burns, broken bones, cuts, brain damage). **(3)** Organic disorders are deficiency diseases caused by lack of proper vitamins and nutrients or by chemical poisonings, radiation, or unknown causes (e.g., strokes, tumors, ulcers, nervous disorders).
2. By exerting pressure on surrounding tissues, cancer cells can impair functions of these tissues and organs, cut off the blood supply, and even cause death.
3. Cancer cells have larger nuclei, more DNA (cell growth and reproduction are more rapid), a bizarre appearance, harmful functions, and, often, an abnormal chromosome number.
4. **(1)** Carcinogens are cancer-causing chemicals that collect or react in the body and induce cancer. **(2)** Radiation (ultraviolet rays, X-rays, and some radioactive substances) has been found to cause cancer (especially skin cancer and leukemia). **(3)** Viruses are known to cause warts and may also attack and grow in cancerous cells.
5. **(1)** Surgical removal of cancerous tissues is successful if all cancer cells are removed. **(2)** X-ray treatment or treatment with radioactive substances that destroy cancer cells may cause tumors to form. **(3)** Chemotherapy consists of certain chemicals directed at destroying cancer cells. These chemicals usually affect other cells as well and can cause harmful side effects. In the future interleukine-induced white blood cells and monoclonal antibodies with specific harmful chemicals attached may be used.

Since cancer cells divide more frequently than normal cells, the chemical will affect these cells more than the rest of the body.

Unfortunately, cancer chemotherapy also affects other cells in the body. Normally, the most rapidly growing cells of the body are affected first. This explains anemia (lack of red blood cells), loss of hair, sensitive skin, and general deterioration of the patient's health. When the chemotherapy stops, the symptoms are reversed, and hopefully only the cancer cells have been permanently harmed. Repeated chemotherapy treatments can destroy several forms of cancer. Sometimes chemotherapy is used to kill those cancer cells that were not removed in the surgical procedure, thus increasing the probability that the cancer will not start to grow again.

Future Cancer Treatments

The following two experimental cancer treatments hold exceptional promise:

- *Interleukines* are chemicals produced by the body cells that stimulate certain immune system cells to multiply. If some of a cancer patient's white blood cells are grown in interleukine solutions, the cells increase in numbers and activity. When returned to the person's blood stream they attack and kill cancer cells. This procedure is still in the experimental stage.
- *Monoclonial antibodies* can be produced in a laboratory. Scientists have developed antibodies that will attach to specific cancer cells without harming the cancer cell. Researchers are trying to attach a substance to the monoclonial antibody that will either hamper or destroy the cancer.

Biological Terms

Infectious Diseases
infectious disease
pathogen
host
incubation period
exotoxin
endotoxin
pre-formed toxin
food poisoning
toxin
inflammation
communicable disease
droplet infection
contact infection
contamination infection
wound infection
vector-carried infection
immune carrier

Defense Against Infectious Disease
structural defense
pus
fever
antibody
chemotherapy
antibiotic
penicillin

Disorder
disorder
injury
organic disorder
tumor
benign tumor
biopsy
pathologist
malignant tumor
cancer
carcinogenic chemical

Facets
gerontology
clinically dead

Answers begin on page 257.

Review Questions 9C-3

1. List and describe three major types of disorders. Give examples of each.
2. In what ways can benign tumors cause physical difficulties?
3. What are some of the differences between normal body cells and cancer cells?
4. List and describe three possible causes of cancer.
5. List and describe several present cancer treatments.
6. List two treatments that may be used in the future.
7. Why is it important to detect cancer early?

Facet 9C - 1: Aging and Death, pages 255-56

1. List some possible causes of aging.
2. Discuss several criteria that have been used to determine the time of death.

Thought Questions

1. Give examples from Scripture which show how God used diseases or disorders to accomplish His will.
2. Give several reasons man must continually seek new methods of conquering disease. Will man ever conquer all diseases? Why or why not?
3. Does a human soul ever die? What is spiritual death? Support your answers from Scripture.

6. Interleukines and monoclonal antibodies hold promise for future cancer treatments.
7. It is important to detect cancer early so that it will not spread and destroy vital tissues and organs. There is also a greater chance of removing all cancerous tissues in earlier stages; the prognosis for successful treatment increases the earlier the cancer is found.

Answers–Facet 9C-1

1. **(1)** Wear and tear on the body has a cumulative effect. **(2)** Continual harmful random mutations in body cells accumulate. **(3)** High body temperatures cause more rapid body metabolism. **(4)** Waste accumulation in cells (lipofuscin) may impair cell function. **(5)** Aging and death are genetically programmed into the body. **(6)** One part of the body can transmit aging instructions to another part through complex aging mechanisms. **(7)** As a result of the fall of man, aging is divinely ordained.
2. **(1)** The absence of brain waves for 24-48 hours indicates clinical death. **(2)** Brain waves, heartbeat, and respiration are taken together as criteria. **(3)** Departure of soul and spirit from the body indicates death.

Answers–Thought Questions

1. II Kings 20; Job; Daniel 4; John 9; Luke 7:1-10; Mark 2:1-12
2. Human disease will never be completely conquered. Therefore, methods of controlling and preventing diseases need continual improvement.
3. The human soul is eternal. Spiritual death is eternal separation from God (Matt. 25:41-46, 13:42, 25:30; John 3:15-18).

THE KINGDOM PROTISTA
MICROBIOLOGY PART II

TEN

Time Frame
10A: 1-2 periods
10B: 1-2 periods
The more laboratory activities, the less class time can be spent on the chapter. With laboratory activities the entire chapter can be covered in 5-6 periods.

Laboratory Activities
10A–*The Protozoans* can take up to 2 periods, depending upon how many organisms the students observe and how many organisms are live or preserved.
10B–*The Algae* can take up to 2 periods. There are a number of sections which the students can do at home without equipment. Select sections of the exercise that contain organisms the students are expected to recognize for testing purposes. Tell them they must be able to recognize the organism, its structures, and its phylum.

10A - The Protozoans

Observing drops of pond water with a microscope can be fascinating. An amazing variety of microorganisms whiz past, roll by, float along in microcurrents, or just sit there. Some appear to be globs; others have perfectly geometric shapes. Some are transparent; others are shades of green, yellow, red, blue, and a host of other colors. Some appear tiny while others seem huge. If you take a drop of water from an area just millimeters away from where you took the first drop, you may find completely different organisms.

Although some of the organisms that you observe in pond water may belong to various kingdoms, most of them are in the **kingdom Protista.** Do not get the idea that protists are all small, insignificant organisms. On the contrary, some of them are relatively large; some have played major roles in history being responsible for the defeat of great armies; and currently, many of them play a major role in our environment similar to that of the land plants by manufacturing a good share of the oxygen we breathe.

10–Microbiology Part II: The Kingdom Protista

Protozoans and algae are standard topics in high school biology classes. They are interesting, significant, can easily be observed in the classroom, and illustrate well the ''unseen world around us.'' They are good topics to teach, but there are several pitfalls that a teacher must be careful to avoid.

First, do not spend time stressing cilia and flagella, spiral chloroplasts and filaments, pseudopodia, and pyrenoids in such a way that more important aspects of this kingdom are omitted. What these organisms do in the environment should be the primary reason for learning them. Do not slight the structures and their functions, but do not make them an end in themselves.

Second, do not become so enamored with looking at the ''critters'' through the microscope that students lose sight of what protozoans and algae truly are. If the exercise becomes one of finding, focusing, drawing, and labeling as ends in themselves rather than observation and appreciation, the true value is lost. Often, drawing and labeling is one of the primary methods of getting students to observe and appreciate. But make sure that the stress is on the organism, not the drawing.

Third, some people are so interested in the peculiarity of these critters that they spend time in class showing everything from microbes in termite intestines stained hot pink from the red-dyed wood the termites ingested to electron micrographs of paramecia stimulated by LSD. A little of this type of material goes a long way and can distract from what the organisms are really like and really doing.

Focus must be kept on the organism and its role in nature–not its place in the laboratory, even though that is where it is being studied.

algae: (L. ALGA, seaweed)

ectoplasm: ecto- (Gk. ECTOS, outside) + -plasm (to mold)

endoplasm: endo- (within) + -plasm (to mold)

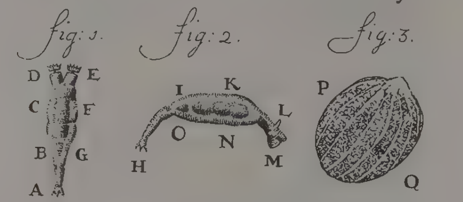
Refer students to Appendix B (pp. 653-54). This can be used as a summary of the classifications studied and a place to clear up the minor confusions which often come as students study the classification of organisms. Refer to this appendix often.

Monera and cyanobacteria were studied in Chapter 9 (p. 233).

Protozoans and algae

The kingdom Protista has two subkingdoms, the *Protozoa* (protozoans) and the *Protophyta* (algae). These are convenient groupings of various phyla.

Protozoans are microscopic unicellular (or, occasionally, colonial) organisms which are usually motile. This movement, often quite rapid, prompted Anton van Leeuwenhoek to describe protozoans as "animalcules" and classify them



10A-1 *Many of Leeuwenhoek's animalcules were protozoans.*

in the animal kingdom. Most protozoans are aquatic, but many are found in the soil. A large number are parasitic. Most protozoans are heterotrophic, but some are both autotrophic and heterotrophic. Protozoans are divided into four phyla based on their means of locomotion.

Algae* have been called the "grass of many waters." In fact, every natural water supply contains some type of alga. Most are microscopic unicellular or colonial organisms. Algae may appear to be floating mats of green slime or velvety coatings on submerged rocks. Their presence may color water various shades of red, brown, blue, or green. You can find algae growing on soil, rocks, trees, and inside small animals. A few algae form very large colonies–some reach over 30 m (98 ft.). Since algae are generally photosynthetic, at one time taxonomists placed them in kingdom Plantae. Today many scientists recognize five algal phyla in the kingdom Protista. A sixth group, the blue-green algae, is procaryotic and, therefore, placed in the kingdom Monera as cyanobacteria. The eucaryotic algal phyla are discussed in the next section of this chapter.

The protozoans

The term "protozoans" means "first animals." Some early microscopists believed that these "animalcules" gave rise to larger animals, which in turn gave rise to larger animals. This concept is evolutionary and shows an ignorance of the complexity of these tiny organisms. In the space of a single cell, protozoans perform all the functions necessary to maintain their living condition.

Their small size helps protozoans in certain functions. The protozoans, being in a moist environment, merely exchange dissolved gasses between their cytoplasm and their surroundings. Soluble wastes diffuse from protozoan cytoplasm through their membranes into the environment. However, securing and digesting food, response to conditions, movement, and reproduction are not simple tasks. Even though in humans each of these activities requires hundreds of thousands of cells, every protozoan cell can, by some method, accomplish these difficult tasks. Finding out what protozoans do, how they do it, and watching them do it are some of the most interesting activities in introductory biological studies.

Phylum Sarcodina: The Sarcodines

Members of the **phylum Sarcodina** (sar koh DYE nuh) are characterized by their lack of a standard body shape. These single-celled protists are enclosed in a flexible plasma membrane that allows them to constantly change their shape. When dormant, the animal may be nearly spherical. When moving or feeding, it will form numerous extensions of its body that function as "false feet." Some species of sarcodines construct and inhabit shells. Sarcodines live in a variety of habitats, including fresh water, the sea floor, and the human mouth and intestine.

Ameba: a typical sarcodine

Amoeba proteus, the common ameba, looks like little more than a blotch of gray jelly. Usually amebas are not swimmers but are part of the slimy covering of submerged rocks or plants. Here they ingest organic debris and small microorganisms. Like other sarcodines, amebas do not form colonies.

The cytoplasm in the ameba is divided into two types: the clear *ectoplasm** found along the plasma membrane and the *endoplasm,** the cytoplasm in the interior of the animal. A single, disc-shaped

It is ideal to use laboratory activities with this material. It can be profitable to spend as much time in laboratory activities as one does in lecture in this chapter.

This unit is ideal for a short laboratory practical test section. On the test day set up several microscopes and/or dishes with observable organisms in them. These are called "test stations" and are usually lettered. As the last section of the test, have students go to the test stations and identify the various organisms, their phyla, the indicated structures, or their functions. The questions may either appear as numbered entries on the printed test the students are using or be written on a card at the test station. There may be more than one question at each test station.

Unless the class is small, it may be necessary to set up duplicates of each test station. It is also wise to have some students start by doing the lab practical section of the test, and then, as they finish and sit down to work on the rest of the test, have other students go to the test stations.

Use preserved slides with covered slide labels. Many microscopes have pointers in their eyepieces, which can be used to point out structures. Organisms in dishes or dissection pans may have pins with colored heads stuck into various structures for the students to identify.

Laboratory practice tests are common in college courses. Some of them take hours and may have hundreds of questions. It can help students to have a taste of this kind of testing in high school. It can also help stress careful laboratory work. Now it is not only "see, draw, label, and forget (memorize text pictures for test)" but "see, draw, label, and remember, since I may see it again."

When planning a laboratory practical section of a test, be sure to inform students of the possible technique before using it. Many future units can also have laboratory practical sections on their tests (especially Chapters 11-17). Consider telling students

10A-2 Amoeba proteus *stained*

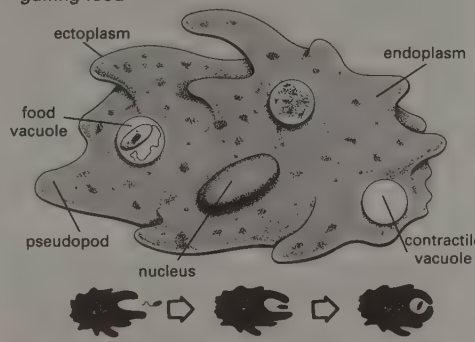
nucleus controls all the metabolic activities of the cell. *Contractile vacuoles* collect and eliminate water, regulating the amount of water in the ameba.

The most outstanding feature of the ameba is its **ameboid movement.** When an ameba moves, its endoplasm streams toward one area of the plasma membrane, causing a bulge to form. This bulge is gradually extended into a long **pseudopod*** (SOO duh POD). The entire cytoplasm of the ameba may flow into a pseudopod and draw the plasma membrane with it, causing the animal to move.

The ameba can respond to a variety of stimuli, generally by a change in the speed or direction of movement. Such actions in response to stimuli are called **taxes** (singular, *taxis).* For example, if a floating ameba touches a solid object, it will move toward and adhere to the object. But the response to touch varies under certain circumstances. If an attached ameba is touched with a glass rod, it will retreat from the stimulus. Amebas will approach an area containing substances diffused from foods and recoil from an area of high saltiness.

Once the ameba has located and selected food (by taxes amebas do show "food preferences"), it uses pseudopods to engulf it. The food material, such as algae or other protozoans, is thus sealed into a *food vacuole* within the ameba. Lysosomes in the cytoplasm fuse with the food vacuole and deposit their enzymatic contents into it, and digestion proceeds within the vacuole. The soluble foods then diffuse into the cytoplasm, and the insoluble materials that remain are egested.

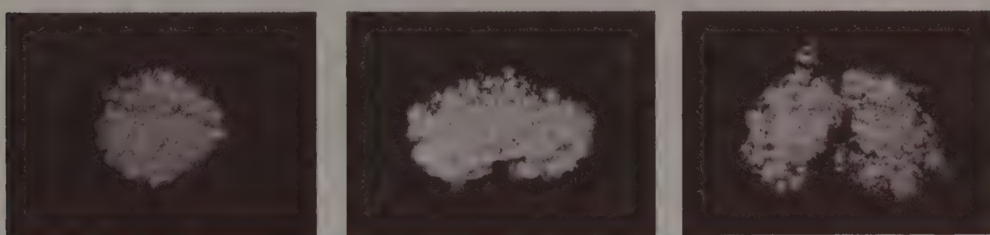
10A-3 *Typical structures of an ameba; an ameba engulfing food*



When an ameba reaches a maximum size, it divides into 2 daughter cells (under normal conditions, about every 3 days). The process begins with the replication of the genetic material of the ameba. Mitosis occurs, and the cytoplasm divides, resulting in 2 complete, functional daughter amebas in about 30 min. Amebas are not known to reproduce sexually.

Some ameba species will respond to life-threatening conditions such as dryness or lack of food by becoming a *cyst**, an inactive cell with a tough wall. These dormant organisms become active upon the return of favorable conditions.

10A-4 *An ameba dividing. Beginning to divide (left), about 18 minutes later (middle), and about 20 minutes after the beginning (right).*



pseudopod or **pseudopodium:** pseudo- (Gk. PSEUDES, false) + -pod or -ped (PODOS, foot)

cyst: (pouch)

Visual 10A-1 may be used to teach about the phylum Sarcodina.

Every high school biology student should be given the opportunity to observe living protozoans. It brings to reality the microscopic world so easily talked about but not readily visualized.

that if a structure is studied in a laboratory activity or if the actual specimen is viewed in class, they should be prepared to see it on a laboratory practical section of the next test.

10A–The Protozoans

Notes–Chapter 10A

Protozoans are standard topics for high school biology classes. The tales told by last year's class to this year's students can cause excitement and anticipation. Do not ignore this motivating tool, but do not expect the students to learn the material merely for the joy of the ameba hunt and the excitement of the paramecium chase. Many hunt and chase without understanding, thus defeating the purpose of the motivational tool. Take time to build anticipation and increase the learning value by adequately covering the significance of the

Objectives–Chapter 10A

- ❑ Describe and give examples of the four protozoan phyla. Be able to classify by sight several typical, but unknown, protozoans.
- ❑ Identify the ameba, euglena, and paramecium.
- ❑ Identify and give the functions of the basic structures of the ameba, euglena, and paramecium.
- ❑ Describe the various methods of locomotion, reproduction, and food acquisition in the ameba, euglena, and paramecium.
- ❑ List several economic effects of the protozoans.
- ❑ Describe malaria: its causes, its historical significance, and how it is prevented.

This box contains supplemental material which students may read, but it need not be included in lecture except as side notes.

There are no terms from this box listed in the Biological Terms section at the end of the chapter. Be sure to inform students of any information from this box that they are expected to know for testing purposes. There are dozens of other protozoans students would find interesting to research.

Occasionally, members of a *Volox* colony will develop gametes, enabling sexual reproduction to occur in the colony.

Other Protozoans

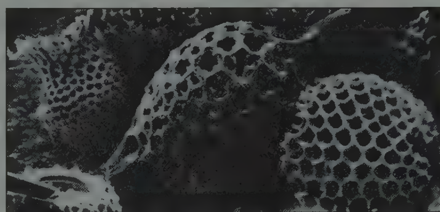
In our study of the protozoans one typical or important example has been chosen for each phylum. There are many other examples.

Other Sarcodines

Some sarcodine species live as parasites of other organisms. *Entamoeba coli* live in human intestines and *E. gingivalis* live in human mouths, but neither is pathogenic. *E. histolitica*, however, is a human pathogen (see page 266).

Many sarcodines form *tests* or shells around themselves and then send out their pseudopods through holes in the test. The *foraminiferans* are tested ocean bottom dwellers. Most foraminiferans form tests of calcium carbonate. When they die their shells add to the ooze on the ocean bottom.

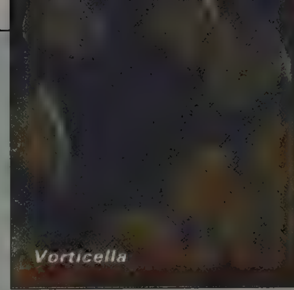
An electron micrograph of radiolarian tests



The *radiolarians* form silicon tests and also contribute to the ocean bottom ooze. About a third of the ocean floor is covered with this ooze which may be up to 4,000 m (12,000 ft.) thick. This is impressive when you consider that 1 g (0.035 oz.) may have 50,000 sarcodine tests.

Other Ciliates

The *Stentor* is a giant among protozoans, reaching a size of 2.5 mm (0.1 in.). This trumpet-shaped organism has a ring of cilia about its gullet. The cilia generate a current that draws food into the gullet. A hungry stentor could consume 100 small protozoans per minute.



Vorticella

Vorticella, a ciliate which lives attached by a corkscrew-shaped stalk to a submerged object, has cilia only on the top.

Other Flagellates

The *Volvox* is a small green protozoan with two short flagella. These flagellates join to form large hollow spherical colonies that move in a slow-rolling fashion. The members of the colony are joined by a geometric latticework of cytoplasmic strands. Miniature daughter colonies, formed as a result of asexual reproduction, often float within the adult colony.

Flagellates of the genus *Trichonympha* actually keep many termite species alive. Many termites ingest wood but are unable to digest the cellulose in it. Living in the gut of the termite, these flagellates produce enzymes that digest the cellulose for themselves and for the termite host. The protozoan has a safe place to live, and the termite can "eat" wood; therefore, both thrive. If separated, they both perish.

Volvox

Review Questions 10A-1

1. What are the primary characteristics of the kingdom Protista? What characteristics separate protozoans from monerans?
2. Compare and contrast protozoans with algae.
3. Describe the typical movement of a sarcodine.
4. How do amebas obtain food?
5. What is a taxis and what taxes do ameba have?
6. Describe the reproduction of an ameba.

protozoans before letting the students dash to the microscopes and cultures.

Do not spend too much time on such things as contractile vacuoles, nuclei, and phagocytosis. Since these were covered in previous chapters, the material is now review and should be reinforced by the questions and activities in the laboratory exercise. The text is relatively clear about such matters, and with well-asked questions by the instructor, the students should be able to grasp such materials by themselves. Instead, spend class time discussing the ecological significance of protozoans, the pathogenic varieties, and the interesting and unusual activities of various examples.

For example, spending hours on the reproductive cycles of these organisms is not as significant as knowing that many of them have different types of sexual reproduction in which genetic information is exchanged. Knowing that they usually reproduce asexually, reproducing sexually only under unfavorable conditions, is more important than labeling diagrams of the stages of their sexual reproduction. Knowing that euglenas are photosynthetic organisms is significant only when their unusual habitats are described.

A box in this chapter deals with three human diseases caused by protozoans. All of them are common in the world today, even though they probably are not diseases which students or people they know have had. It is suggested that students read this box and that the teacher mention each disease (with the exception of malaria), an interesting point or two about it, and the organism's phylum. The malarial parasite is one of the main organisms spoken of in the chapter; consider using the box material to enhance the teaching of that phylum.

Phylum Ciliophora: The Ciliates

The **ciliates** (SIL ee ihts), members of the **phylum Ciliophora*** (SIL ee AH foh ruh), are among the most intricate and fascinating organisms in the kingdom Protista. These organisms may be up to 3 mm (0.12 in.) long, quite large for a protist, and exist in a variety of shapes.

The characteristic that distinguishes this group is the possession of *cilia*. The cilia of these protozoans beat rhythmically to move either the organism or its food. The arrangement of the cilia varies. Some ciliates are completely covered with cilia; others bear rings or patches of cilia. Most ciliates are free-swimming, but a few can attach to submerged objects.

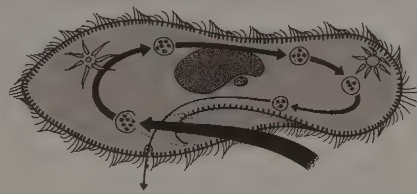
Paramecium: a typical ciliate

Protozoans of the genus *Paramecium* (PEHR uh MEE see um) are common, free-swimming inhabitants of stagnant lakes and ponds. Paramecia have a distinctive slipper shape maintained by the **pellicle,*** a firm yet flexible covering. The cilia that completely cover the paramecium can beat either forwards or backwards, enabling the organism to turn, rotate, and travel in any direction.

The kidney-shaped **macronucleus*** is the most conspicuous feature of the cytoplasm. The macronucleus appears to be multiple copies of the genetic material of the cell. These copies of genes probably aid the high metabolism typical of most ciliates. The smaller **micronucleus*** functions as the reproductive nucleus.

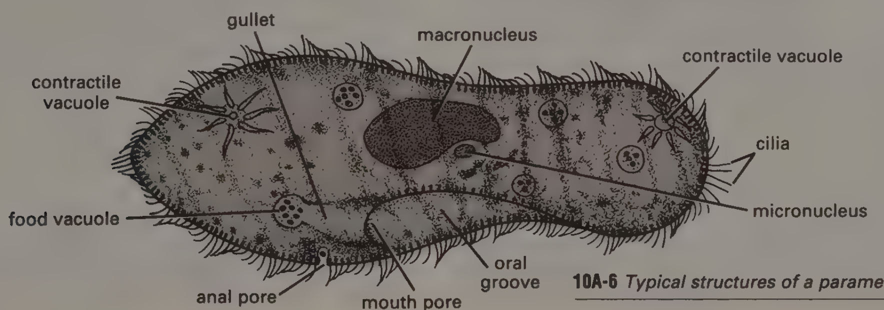
The body of the paramecium has a funnel-shaped indentation called the **oral groove.** Cilia that line the oral groove sweep food material through the **mouth pore** into a short, blind pocket called the *gullet*. As food is directed into the gullet, an enlargement forms at the gullet end. This pocket eventually is pinched off, becoming a *food vacuole*. The vacuole is then circulated throughout the cytoplasm, where enzymes from lysosomes digest the food. Any indigestible material is expelled from the paramecium through the anal pore, a tiny opening in the cell.

10A-5 *The path of a food vacuole in a paramecium*



The paramecium has two star-shaped *contractile vacuoles*. The rays of the stars are *canals* that collect excess cell water and empty it into the vacuole at the center. When the vacuole is full, the water is expelled from the cell. The swelling and squeezing of these vacuoles is often seen under the microscope. The concentration of salts in the paramecium's environment determines the rate at which these organelles operate.

Paramecia tend to swim in a forward spiral motion. When the animal collides with an obstacle, it will stop, back up, turn slightly, then move forward again. Paramecia will also avoid temperature extremes and most chemicals in the same way. This *avoiding reaction* is an example of taxis in paramecia. Acidity attracts these protozoans. Because bacteria tend to thrive in acidic



10A-6 *Typical structures of a paramecium*

Ciliophora: Cilia- or Cilio- (eyelid) + -phora (Gk. PHERIEN, to bear)

pellicle: (L. PELLIS, skin)

macronucleus: macro- (Gk. MAKROS, large) + -nucleus (central part)

micronucleus: micro- (small) + -nucleus (central part)

Visual 10A-2 may be used to teach the phylum Ciliophora.

Note the waves of cilia movement.

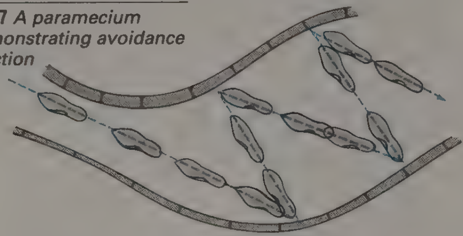
Answers–Review Questions 10A-1

1. **(1)** Appendix B (p. 653); **(2)** primarily protozoans are eucaryotic, while monerans are procaryotic.
2. All protozoans and most algae are microscopic. Protozoans are usually unicellular; algae may be unicellular or colonial. Some algal colonies may be sessile; protozoans are usually motile. While algae may appear in water, soil, rocks, trees, or small animals, protozoans are usually aquatic, although some are found in soil. Most protozoans are heterotrophic, but some may be both autotrophic and heterotrophic; algae are usually photosynthetic and possess the various colored pigments that make this possible.
3. The ameba moves by means of pseudopodia in what is called *ameboid movement;* the movement and flow of cytoplasm form a bulge in an area of the plasma membrane; the cytoplasm flows into this bulge until it draws the animal with it.
4. Through taxes the ameba locates food, which it engulfs with pseudopodia. The food is then sealed in a food vacuole and digested by lysosomes.
5. A taxis is an action in response to a stimulus. Taxes are responsible for much of the movement of protozoans and for their ability to locate food materials, foreign objects, and light; the organism needs them for protection and survival. Taxes include response to food, response to danger, and response for attachment.
6. When the ameba reaches maximum size, it goes through mitosis in about 30 minutes, dividing into 2 daughter cells. The ameba lacks any known form of sexual reproduction.

Mastigophora: mastigo- (Gk. MASTIX, whip or lash) + -phora (to bear)

Few of the ciliates pose any threat to man. The notable exception is the human intestinal parasite *Balantidium coli*. This organism may cause severe, occasionally fatal, dysentery.

environments, this attraction helps paramecia locate bacteria which serve as their food.



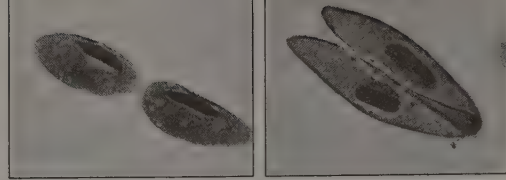
10A-7 *A paramecium demonstrating avoidance reaction*

In response to certain stimuli, **trichocysts** (TRIK uh SISTS), which are tiny organelles under the pellicle, discharge filaments into the water. The function of these filaments is uncertain, but they may be a defense mechanism or a means of attachment.

Reproduction in the paramecium

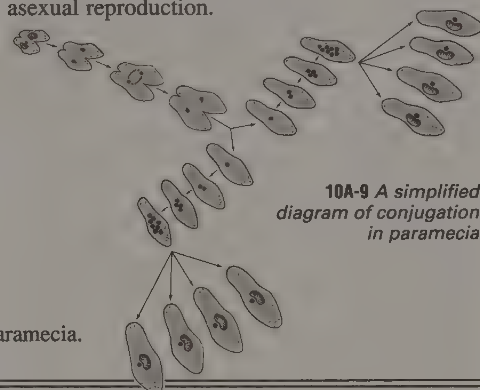
Paramecia go through transverse fission.

Paramecia reproduce by two methods. The first is *asexual binary fission*. In this process the micronucleus divides by mitosis, and the macronucleus divides amitotically. The paramecium elongates, and a second gullet forms. Finally a furrow forms across the middle of the organism, and it divides into two complete daughter paramecia.



10A-8 *A paramecium in fission (left), and paramecia in conjugations (right)*

Paramecia also reproduce by a type of sexual reproduction called **conjugation.** Two paramecia attach to each other by their oral surfaces. Each animal undergoes a variety of nuclear changes. At one point the cells exchange part of their nuclear material through the cytoplasmic bridge. The cells then separate and undergo more nuclear divisions and changes. Finally, each cell divides to form four paramecia. Conjugation allows a mixing of genetic material that is impossible in asexual reproduction.



10A-9 *A simplified diagram of conjugation in paramecia*

Review Questions 10A-2

1. Describe the typical movement of ciliate.
2. How do paramecia obtain food?
3. What taxes do paramecia have?
4. Describe both sexual and asexual reproduction of paramecia.

Visual 10A-3 may be used to teach about the phylum Mastigophora.

Phylum Mastigophora: The Flagellates

The **phylum Mastigophora*** (MAS tih GAH foh ruh) consists of the **flagellates,** those protozoans that propel themselves by means of flagella. All mastigophorans are heterotrophic, but some of them have chlorophyll and can produce their own food. Such organisms are both autotrophic and heterotrophic. These "plant-animals" were a source of classification problems. Since the flagellates are unicellular or colonial, scientists now place all of them in the kingdom Protista.

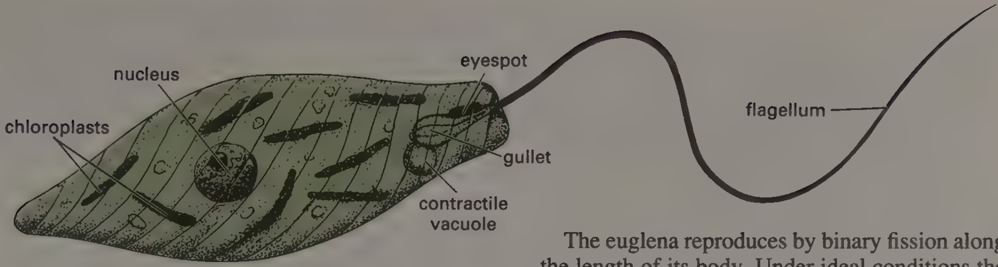
Some flagellates are free-swimming while others are fixed to some solid object. Some form elaborate colonies large enough to be seen with the unaided eye while others are among the smallest of the protozoans. They abound in salt and fresh waters, as well as in the soil. Many are parasitic and some are pathogenic in man and animals.

Euglena: a typical flagellate

The genus *Euglena* (yoo GLEE nuh) contains tiny freshwater flagellates. Each of these spindle-shaped organisms has a single anterior flagellum

Answers–Review Questions 10A-2

1. Ciliates move by cilia (hairlike projections). Some have cilia all over them; others have cilia in only certain areas. Cilia are coordinated in their movement.
2. The paramecium uses cilia lining the oral groove to sweep food through the mouth pore into the gullet. A food vacuole forms at the end of the gullet, and lysosomes digest the food.
3. The avoiding reaction is an example of a paramecium taxis. When a paramecium hits something, it will back up, change direction slightly, and then go again. Paramecia go toward acidic areas to find food.
4. The paramecium performs asexual binary fission, the micronucleus dividing mitotically and the macronucleus amitotically. The animal elongates, a second gullet forms, a furrow forms across the middle of the organism, and it finally divides into 2 complete daughter cells. The paramecium performs conjugation, in which a cytoplasmic bulge connects 2 organisms; they exchange nuclear material, separate, and then divide to form 4 new cells.



10A-10 *Typical structures of a euglena*

for locomotion. The euglena also has chlorophyll in chloroplasts. Under ideal conditions the euglena survives primarily on the products of photosynthesis. Even under these conditions, however, the euglena is also saprophytic, absorbing dissolved food from the surrounding environment. In low light or darkness, its photosynthetic apparatus shuts down and even degenerates. The euglena can sustain itself on dissolved nutrients.

The body of the euglena is covered with a shape-sustaining *pellicle*. At the anterior end of the animal a small gullet enlarges into a reservoir. Though the reservoir looks much like a mouth, euglenas probably do not ingest food through the gullet and reservoir. Near the reservoir is a tiny, red, light-sensitive *eyespot*. The euglena has a single nucleus containing a large nucleolus. Like most protozoans, the euglena has a *contractile vacuole* which maintains the organism's water balance by expelling excess water from the cytoplasm into the reservoir.

Euglenas usually move by whirling their anterior flagella to pull themselves through the water. They can also move by a modified ameboid movement. The euglena draws its cytoplasm in, making itself almost completely round, and then re-extends itself forward. Employing this **euglenoid movement,** the animal can propel itself with a wormlike motion.

10A-11 *Euglenoid movement*

The euglena reproduces by binary fission along the length of its body. Under ideal conditions the euglena will reproduce about once a day. Sexual reproduction in the euglena is unknown.

Phylum Sporozoa: The Sporozoans

The members of the **phylum Sporozoa** (SPOHR uh ZOH uh) are unique among protozoans since, as adults, they do not have pseudopods, cilia, flagella, or any other special structures for locomotion. As the name implies, sporozoans form *spores* at some stage of their life cycle. First, the nucleus of the sporozoan divides several times, and a small amount of cytoplasm gathers around each nucleus. Then the organism breaks apart, and each of the nuclei becomes a spore which may be surrounded by protective coats.

All sporozoans are parasitic, often having complex life cycles involving a number of animal hosts. They feed by absorbing dissolved materials from the host's cells and body fluids. Asexual reproduction may occur by spore formation or by cell division. Many sporozoans also have some means of sexual reproduction.

Plasmodium: a sporozoan

A devastating disease of the tropics is **malaria,** an illness that causes severe discomfort and, frequently, death. Malaria, meaning "bad air," was once believed to be caused by tropical swamp air. Some claim that malaria is the most significant disease of man, directly or indirectly causing more deaths than any other disease and significantly influencing human events.

In the late 1800s the French attempted to dig a canal across Central America that would join the Atlantic Ocean and the Pacific Ocean. The workmen sent to accomplish this task soon fell ill; many died from yellow fever (caused by a virus) or malaria. This epidemic was one crucial reason

Quinine is obtained from the bark of the cinchona tree, but it does not cure malaria. Today scientists realize that prevention is the best control. The *Anopheles* mosquito has been wiped out in many areas of the world. In the United States today, malaria occurs only in people who have traveled to where *Anopheles* mosquitoes and malaria exist and in a few people who contract it from *Anopheles* mosquitoes here in America that have bitten carriers of the disease. By using drugs that kill the parasite in the blood and other drugs that work outside the blood, people can be cured of several kinds of malaria.

This box contains supplemental material which should be studied by most students. Omit the box if time is limited. The box presents information about malaria, amebic dysentery, and African sleeping sickness.

There are no terms in this box which are listed in the Biological Terms section at the end of the chapter.

The significance of protozoan pathogens in animals is evidenced in the economy of many African nations. Although the area may be ideal for raising cattle, the presence of pathogenic protozoans makes it unprofitable.

The saliva of the mosquito prevents the blood from clotting in the mosquito's sucking mouthparts and causes the red bump on the host after the mosquito has fed. There are various forms of human malaria, each caused by a different species of this genus. There are various forms of malaria caused by other genera and species that affect birds, cattle, etc.

Montezuma, the Aztec King who greeted the first conquistadors, did not willingly part with all the gold the Spanish demanded of him. He had his revenge but not by "spear point." Many of the Spanish soldiers died of infections of *E. histolytica* as they carried away the gold. Sometimes the disease is called Montezuma's Revenge or the Aztec Curse. It is amebic dysentery that makes the traveler's warning "Don't drink the water!" good advice.

Protozoan Diseases

Although most protozoans live harmlessly in the soil or water, there are a good number that live inside other organisms. In some cases the protozoan is beneficial to its host (as in the cellulose-digesting ciliates found in termites). In many cases the protozoans appear harmless. In some cases, however, they are pathogenic.

Most protozoan-caused diseases affect animals. There are, however, several human diseases caused by protozoans. Most of them are rare, but three of them have sometimes changed the course of history and are still health problems today.

Malaria (Sporozoan *Plasmodium*)

Life cycle: The female *Anopheles* mosquito becomes infected by drinking the blood of a human who has malaria. The *Plasmodium* cells mature and develop in the mosquito and migrate to the insect's salivary gland. Before feeding on the blood of another human, the infected mosquito injects saliva into the puncture wound of its new victim and thereby puts the parasite back into the human bloodstream.

One of the mosquitoes common in the U.S. (left) and the *Anopheles* mosquito (right)

In the human, the spindle-shaped *Plasmodium* cells penetrate liver cells where they grow and reproduce in about two weeks. The parasite then enters red blood cells and reproduces. The blood cells burst, releasing cells that may invade other blood cells and repeat this reproductive process. When a mosquito feeds on an infected individual, it ingests the parasite and thus completes the life cycle.

Symptoms and cures: The periodic rupturing of red blood cells releases toxins that are associated with violent fits of chills and fever. The person also suffers anemia (inability of the blood to carry oxygen) and an enlarged spleen. The most successful method of controlling the disease has been to limit human exposure to *Anopheles* mosquitoes. Today a series of drugs can be used to prevent and cure the disease.

Amoebic Dysentery (Sarcodina *Entamoeba histolytica*)

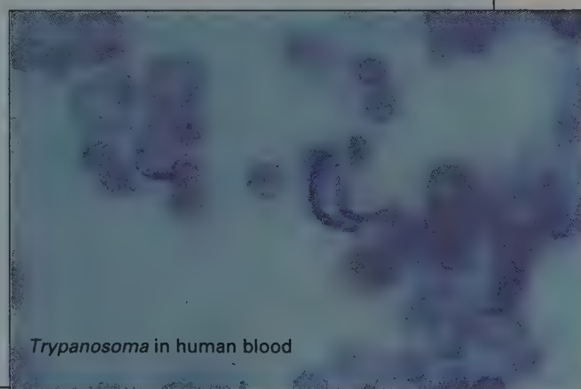
Life cycle: In some areas of the world large portions of the population are *carriers,* (humans with *E. histolytica* in their intestines but not suffering from the disease). *E. histolytica* forms cysts that exit the body in feces. The cysts can live outside the body in moist, warm conditions. The cysts are transferred to humans by contaminated water and houseflies which bring the cysts to food.

Symptoms and cures: In many people *E. histolitica* eats the cells of the intestinal walls causing ulceration. This results in severe diarrhea and can lead to death. In times past the disease was often fatal, but today various drugs can kill the parasite.

African Sleeping Sickness (Mastigophora *Trypanosoma;* different species cause different forms of the disease)

Life cycle: African sleeping sickness is passed from person to person by the blood-sucking tsetse fly which is found only in Africa. The *Trypanosoma* grows and divides in the insect's intestine and then invades the salivary glands. When the fly bites a person the protozoan may enter the blood stream. In the blood stream the parasite reproduces.

Symptoms and cures: After the protozoan has been in the blood it may invade the central nervous system and cause inflammation of the brain resulting in weakness, mental lethargy, and sleepiness which lead to continuous sleep and, possibly, death. Controlling the tsetse fly controls the disease. Drugs can now be given to those suffering from the disease.



Trypanosoma in human blood

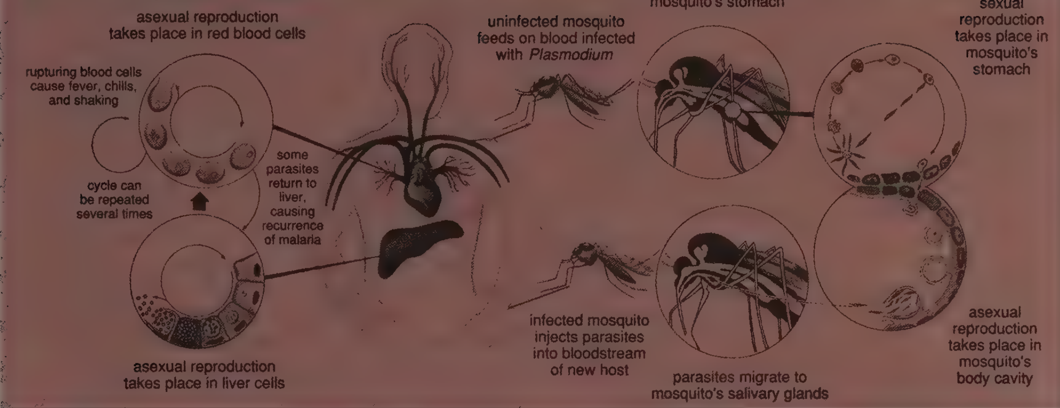
At any given time more than a million Africans are suffering from African sleeping sickness.

Reproducing asexually in both the fly and the human, the malarial protozoan can increase its numbers rapidly.

Answers–Review Questions 10A-3

1. The euglena moves by a flagellum, a single hairlike projection, in a whiplike motion or a modified ameboid movement.
2. The euglena is primarily photosynthetic but is also saprophytic. It absorbs dissolved food from the surrounding environment.
3. The euglena has chlorophyll which is used in photosynthesis. Because it is photosynthetic, it has characteristics of the plant kingdom; however, it can absorb food and can move–characteristics which can classify it as an animal.
4. Euglenas use their eyespots to locate light and then travel toward it.
5. All sporozoans are parasites, many of which cause disease in organisms. Malaria is the most common human disease caused by a sporozoan.
6. **(1)** The female *Anopheles* becomes infected by drinking the blood of an infected human. **(2)** *Plasmodium* cells mature in the mosquito and migrate to its salivary glands. **(3)** *Plasmodium* cells are injected into the human by the feeding mosquito. **(4)** The *Plasmodium* penetrates liver cells of the human, where it grows and reproduces. **(5)** Eventually it invades the bloodstream,

10A-12 Life Cycle of Plasmodium



Since the time spent in the liver and red blood cells is regular, the chills and fever fits are also regular and of increasing severity if not treated.

Have students learn a generalized life cycle of the malarial organism. Note that *Plasmodium* is a genus name. There is a structure in some fungi called a plasmodium.

why the French project was canceled. The door opened for the United States to build a canal. In 1880, Dr. Charles Laveran discovered the malarial protozoan, a member of the genus *Plasmodium* (plaz MOH dee um). Later research unlocked the complete life cycle of this sporozoan.

Knowing the *Plasmodium* life cycle has helped to control malaria in many areas of the world. When building the Panama Canal, for example, Col. William Gorgas of the United States Army ordered swamps drained and brush cleared in the area where Americans were working. Destroying the mosquito breeding areas eliminated the organisms that transmitted malaria and also yellow fever. This enabled the Americans to finish the canal.

Biological Terms

kingdom Protista
protozoans
algae

The Sarcodines
phylum Sarcodina
ameboid movement
pseudopod
taxes (sing., taxis)

The Ciliates
ciliate
phylum Ciliophora
pellicle
macronucleus
micronucleus
oral groove
mouth pore
trichocyst
conjugation

The Flagellates
phylum Mastigophora
flagellate
euglenoid movement

The Sporozoans
phylum Sporozoa
malaria

Review Questions 10A-3

1. Describe the typical methods of movement used by euglenas.
2. Describe the methods euglenas use to obtain food (energy).
3. Why was classifying the euglena difficult for many early microbiologists?
4. What taxes do euglena have?
5. Why is Sporozoa a significant protozoan phylum?
6. Describe the life cycle of the *Plasmodium*.
7. List six protozoans (other than the ameba, the paramecium, the euglena, and the *Plasmodium*) and tell their significance.
8. When visiting certain countries, such as Mexico, people are often warned not to drink the water in smaller towns. Why is this good advice?
9. Why do people in the U.S. not have to worry about catching African sleeping sickness from a person with the disease who visits in their home?

Thought Question

Why is it inaccurate to call a protozoan a simple organism?

enters red blood cells, and reproduces. **(6)** Blood cells rupture and release many *Plasmodium* cells that may reinvade blood cells and repeat *Plasmodium* formation; the rupturing is associated with chills and fever.

*7. **(1)** *Trichonympha*–flagellates that digest cellulose for termites; **(2)** foraminiferans–composed of lime; their cell walls form natural chalk (white cliffs of Dover); **(3)***Balantidium coli*–human parasite, dysentery; **(4)** *Trypanosoma*–causes African sleeping sickness; **(5)** *Volvox*–a small green protozoan that forms hollow spherical colonies; **(6)** *Globigerina*–the shells sink to the bottom of the ocean and form the ooze on about one-third of the ocean floor. Others are possible.

*8. *Entamoeba histolytica,* which causes amebic dysentery, can form cysts which remain alive in water.

*9. The disease is transmitted by a vector, the tsetse fly, which is found only in Africa.

*From a box.

Answer–Thought Question

Protozoans are very complex; they perform all the necessary life processes within a single cell. They can be considered more complex than any individual cell in the human body.

10B - The Algae

plankton: (Gk. PLANKTOS, wandering)

zooplankton: zoo- (Gk. ZOION, animal or living being) + -plankton (wandering)

phytoplankton: phyto- (plant) + -plankton (wandering)

To most people algae are either the nuisance that clouds the swimming pool water or the slimy green mat floating on the pond. The green threads growing on rocks in a stream seem insignificant when compared to wheat, corn, or fruit trees. But to fish and indirectly most other aquatic organisms as well, algae are the staff of life.

Algae are the photosynthetic organisms that capture the sun's energy in aquatic environments. In any natural water supply there are thousands of tiny floating organisms called **plankton.*** There are two types of plankton:

❑ **zooplankton*** (ZOH uh PLANGK tun), which are tiny floating animals or protozoans; and

❑ **phytoplankton*** (FYE toh PLANGK tun), which are tiny floating photosynthetic organisms, predominantly algae.

Other material about plankton appears on pages 477-78; other material about producer organisms, on pages 462-65.

Phytoplankton manufacture not only their own food but also the food for zooplankton and many larger organisms. Thus, they are the *primary food-producing organisms* in aquatic environments. Many fish have a specialized feeding apparatus which permits them to strain plankton from the water. Even the largest known living animal, the great blue whale, weighing over 107 metric tons (236,000 lb.), exists by straining the ocean's "plankton soup."

The rate of photosynthesis is faster in aquatic environments because there can be more chlorophyll per square yard in the water than on the land. Also, less of the product is used to build supporting structures like roots and trunks since the algal structures require little support in the water.

Man has found various uses for algae. In some areas of the world men use sea algae as a natural fertilizer. In recent times algae have been processed to obtain potash, iodine, nitrogen, salt, and other products. Algae are an inexpensive source of certain vitamins and minerals in the feed of domestic livestock.

Certain reef-building coral organisms contain algae, causing them to build reefs considerably faster when the coral is exposed to light. Also see lichens (pp. 286-87).

In various areas of the world people eat algae. The Japanese cultivate algae as a human food crop. In New England a marine alga called sea kale is eaten as a vegetable. Many algal products are used in food processing. *Irish moss,* an alga which grows along the Atlantic coast, supplies a substance used as a thickener in puddings, jellies, and ice cream.

Some people have begun to look to the sea as a future major source of food for humans. The earth has a limited amount of land suitable for farming, and there is a limit to how much food man can produce in any given spot. **Aquaculture** (the farming of ponds, lakes, and the sea) can produce considerably more organic materials than conventional farming of the same area of land. Algae are an important part of aquaculture, as food for fish and for humans. Many algal food substances are edible and wholesome, but many people consider them undesirable. As demands on other food sources increase, however, eating alga bread or alga cookies may become common.

Algae and other organisms

Although algae are an important food source, they benefit other organisms in other ways as well. The algae in the vast expanses of open ocean carry on about 70% of the oxygen-producing photosynthesis that takes place on our planet. Thus, the oxygen-carbon dioxide cycle appears to depend more on algae than on the rooted green plants to which we normally ascribe oxygen production.

Recent studies regarding space flights have reemphasized the life-sustaining importance of algae. In space man must carry his oxygen and food with him. For an extended space flight, the bulk of these two items would be excessive. Some algae, if supplied with ideal conditions, can increase in size a thousandfold in 24 hr. Algae, which could take carbon dioxide from humans and return both oxygen and a food substance, may be the only means of man's survival during lengthy space travel.

Some organisms exist with algae in other profitable relationships. Some protozoans, for example, have algae in their vacuoles. The algae carry on photosynthesis and supply sugars to the protozoans. Some freshwater organisms appear green because of the algae living inside them, supplying them with food.

Although some algae can exist in a wide variety of habitats, some are quite specific as to the type of environment in which they will grow. Scientists use certain algae as **indicator organisms.** For example, if a water sample taken from a lake

10B–The Algae

Notes–Chapter 10B

The great diversity of algae, so fascinating to a biologist, may become a burden to students. Try not to let this happen. In lectures, emphasize the significance of algae. Discuss the characteristics that keep algae together as a unit and the diversity within those characteristics. The temptation will be to present vast amounts of information in an attempt to "span the spectrum." Spanning the spectrum, a worthy goal, must be done within a solid, simple framework in order to spare students from frustration.

Although algae have major significance in the environment collectively, most of them are relatively insignificant when viewed and studied singly. Be careful not to make too much of what, to many students, will appear to be an insignificant thing. Remind them that the algae they are studying have been chosen as examples; the

Objectives–Chapter 10B

❑ Describe algae's economic and ecological significance.

*❑ Describe and give examples of the five eucaryotic algal phyla.

*❑ Identify and describe the following algae: *Spirogyra,* diatoms, desmids, *Protococcus, Fucus.*

❑ Describe the methods of sexual and asexual reproduction in algae.

❑ Define *bloom condition.* Describe some of the possible effects of a bloom condition of algae.

❑ Define *miracle* and give examples, and explain why the example is a true miracle.

*From a Facet.

has an abundance of certain species of *Oscillatoria* (a blue-green algae), the scientist suspects that the lake is highly polluted with organic materials. Since *Lemanea annulata* is found only in unpolluted streams, quantities of this red alga is generally a sign of clean, flowing water.

Classification of algae

The classification of algae is open for debate. Because of the great differences–and similarities–in various algae, scientists have not agreed on how many algal phyla exist. Taxonomists often place some organisms normally considered algae in protozoan phyla, and sometimes they move certain protozoans to algal phyla. They have not even settled the placement of the algal phyla into kingdoms.

Many scientists agree that the procaryotic algae, the blue-green algae (cyanobacteria), should be in the kingdom Monera. For convenience, scientists generally place the five eucaryotic algal phyla into the kingdom Protista.

The algae are grouped according to the pigments which they contain, the substances which they store as food and the materials which comprise their cell walls. Often the pigments in algae greatly affect their colors. Even within a phylum varying amounts of different pigments create wide ranges of colors.

Algal colonies

Many algae are unicellular, and a number form globular masses of cells held together by a common slime coat. Some algae, however, form highly complex colonies. One of the simpler colonies is a **filament,** a slender, chainlike thread of cells. Some algae form *branched filaments;* others form broad plates or sheets of cells. Some algae form special cells called **holdfasts** that anchor them to submerged objects. In large algae the holdfasts may be a group of cells. Algae that grow attached to something are called **sessile*** algae.

An algal colony is called a **thallus.*** A thallus is the body of a plantlike organism which is not differentiated into true leaves, roots, and stems. Often an algal thallus has leaflike, stemlike, and even rootlike structures. But algae do not form tissues or organs. Under a microscope a large algal thallus appears as many intertwined filaments. Each of the algal cells comprising such a colony can live independently in the environment where the thallus grows and (at least theoretically) can become a completely new thallus.

Some algae form **air bladders,** small air-filled spaces that cause the thallus to float. Often a large algal thallus will have a holdfast on one end and air bladders on the other end, causing them to appear to stand upright in the water.

10B-1 *Kelp with air bladders*

sessile: (L. SESSILIS, capable of being a seat)

thallus: (Gk. THALLEIN, to sprout)

One species of green alga normally has flagella, a cell wall, and an eyespot. This alga, however, is often found in vacuoles of the skin cells of a marine flatworm. In such cases the alga lacks flagella, a cell wall, and an eyespot. Outside the flatworm, these structures re-form. Certain nudibranchs (marine animals resembling shell-less snails) have cells in their bodies that contain chloroplasts, presumably from the algae that the animal eats. A nudibranch exposed to enough sunlight can carry on photosynthesis so well that it will give off oxygen.

Review Questions 10B-1

1. List several ways in which algae are (a) harmful and (b) beneficial.
2. What characteristics separate algae from (a) the protozoans and (b) the plants?
3. Describe several types of algal colonies.

Some of the larger algae, reaching up to 31 m (100 ft.) long, are able to conduct water through their streamlike structures. Some scientists therefore classify some algae as plants. For convenience, and in keeping with the concept in this book of tissues separating plants from protists, all but the blue-green algae will be classified in the kingdom Protista.

Reproduction in Algae

When an algal colony cell carries on mitosis, resulting in daughter cells, the colony is enlarged. Most algae can also reproduce asexually by various mitotic means.

❑ *Unicellular reproduction* Unicellular algae, of course, form new organisms by mitotic cell division (see *Chlamydomonas,* page 270 and diatoms, page 272).

❑ *Fragmentation* Most algal colonies can reproduce by **fragmentation:** if the colony is broken by a physical disturbance (currents or fish), each section can grow into a complete colony.

ones they are studying are significant in the environment when combined with all the other algae.

Strive to teach a simple, workable knowledge of the group and a recognition of the diversity within it.

A special section covers the five algal phyla in the kingdom Protista (pp. 270-74). A brief description of each phylum is followed by illustrations and descriptions of examples. Tell students they are responsible for only those algae that they study in the laboratory activities. Then carefully choose the sections of the laboratory activities they do and which algae they need to know as examples of phyla or structures.

Answers–Review Questions 10B-1

1. **(a)** Certain algae produce potent poisons that may kill livestock. Others can cause strange odors and tastes in city water supplies and may foul water supplies when they die. **(b)** Algae are beneficial when they perform photosynthesis, providing a vital link in the oxygen and carbon dioxide cycle and capturing sunlight energy for aquatic life. They also serve as natural fertilizer; are used to obtain potash, iodine, nitrogen, salt, vitamins, and minerals; are a food source (kale, seatron, and a thickening agent for puddings, jellies, and ice cream); and form diatomaceous earth.
2. **(a)** Unlike protozoans, most algae are sessile, some having holdfasts; the body of the organism (thallus) consists of filaments; some conduct water through stemlike structures. **(b)** Unlike plants, algae have no tissues or true organs; the body is the thallus.
3. Filament (slender, chainlike thread of cells); branched filaments; broad plates or sheets

Chlorophyta: Chloro- (greenish yellow) + -phyta (plant)

carotenoid: caroten- (L. CAROTA, carrot) + -oid (form or shape)

This special section (pp. 270-74) contains supplemental material which should be studied by most students. Omit the section if time is limited. This section presents examples and descriptions of algae.

The terms **pyrenoid** and **dinoflagellate** and the five eucaryotic algal phyla are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Tell the students which of these algae and structures they must be accountable for. It is suggested that sections of the laboratory exercise be selected that will reinforce the algae and structures that students should know for testing purposes.

It is recommended that students be familiar with the following phyla (groups) and algae:

- ❑ Chlorophyta: desmids, *Protococcus, Spirogyra*
- ❑ Chrysophyta: diatoms
- ❑ Phaeophyta: *Fucus*, kelp
- ❑ Red algae
- ❑ Dinoflagellates

Visual 10B-1 can be used to teach *Ulothrix* and *Oedogonium* characteristics.

Chlorophyta, the Green Algae

Chlorophyta* (klor AH fih tuh), the *green algae,* is one of the largest algal phyla. Most green algae are freshwater organisms; however, many terrestrial and a few marine species exist. Usually green algae are unicellular or form simple colonies, but some marine species form extensive thalli. One green algal species that grows off the coast of Mexico produces leaflike blades that reach 25 cm by 7.5 m (10 in. by 24 ft.). Many green algae produce holdfasts and grow attached to submerged substances, but some unicellular species move by flagella. Many kinds merely float.

Green algae contain chlorophyll *a* and *b* and yellow-orange pigments called *carotenoids** (kuh RAHT uh NOYDZ); therefore, they often appear various shades of yellow green. The chloroplasts in green algae are often unusual. Many cells contain only one large chloroplast of an unusual shape. Such chloroplasts are often used to identify the alga (see *Spirogyra* and *Ulothrix*).

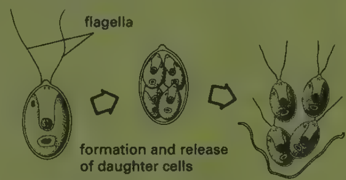
Green algae typically store their food as starch. Large starch granules can often be found around a protein-containing cellular structure, the **pyrenoid** (pye REE NOYD). Pyrenoids probably contain the enzymes necessary for the manufacture of starch from the simple sugars produced by photosynthesis.

Often Chlorophyta is divided into two groups, the unicellular and the filament-forming green algae.

Unicellular Green Algae

Chlamydomonas

Members of this genus are common inhabitants of stagnant freshwater pools. They possess 2 flagella. Asexual reproduction involves the division into 2-8 daughter cells within the cell wall and membrane of the mother cell. As this happens, the parent loses its flagella. Flagella form on the daughter cells just before they are released.



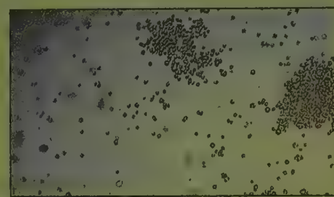
Desmids

Desmids are free-floating algae. Usually they are unicellular, but occasionally cells are joined end to end, forming a filament-like colony. Desmids often are pinched in the middle, forming two symmetrical halves. Often the cell walls have unusual patterns, making desmids some of the most interesting freshwater algae.

Chlorella

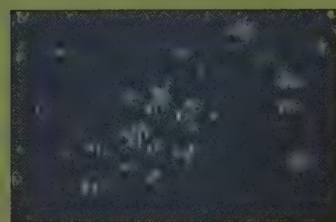
Members of this unicellular aquatic genus are frequently used to study cellular processes like photosynthesis. They often live inside various animals.

Chlorella



Protococcus

This genus contains terrestrial members, many of which grow as a green film on damp rocks or tree bark. *Protococcus* exists unicellularly but may form clumps of several or many cells.

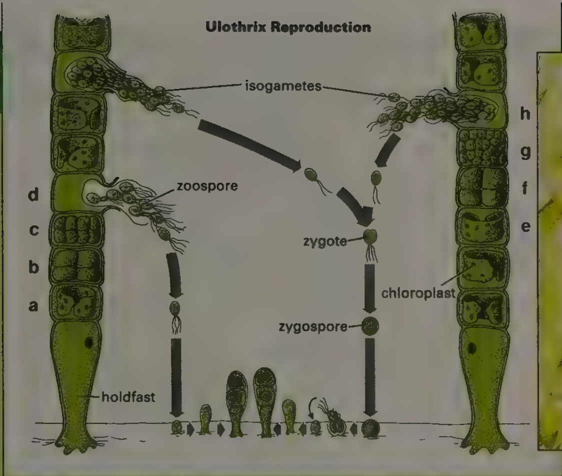


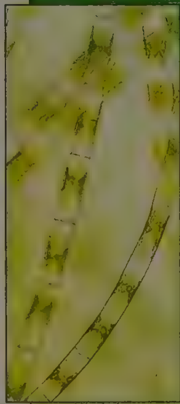
Protococcus

Filament-forming Green Algae

Ulothrix

Ulothrix filaments are usually attached to submerged structures by a holdfast but can be found floating. *Ulothrix* can reproduce asexually by forming from 4-8 zoospores in a single cell (a-d). These zoospores have 4 flagella and





Ulothrix

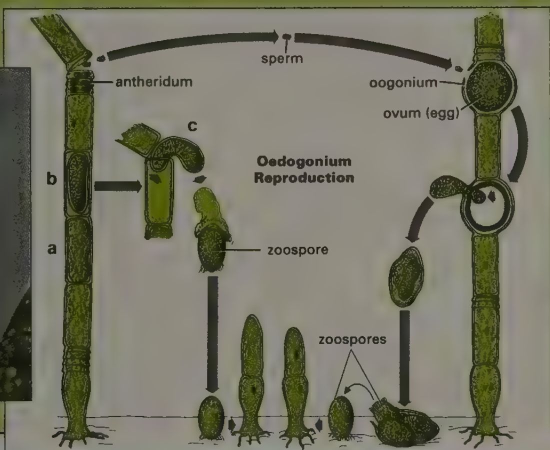
swim away to establish new colonies. Sexually, *Ulothrix* produces from 8-64 isogametes inside a single cell (e-h). Each of these gametes has 2 flagella. When released, they swim, unite, and form a zygote which then becomes a zygospore.

Oedogonium

Oedogonium can reproduce asexually by forming a single, multiflagellate zoospore within a cell.

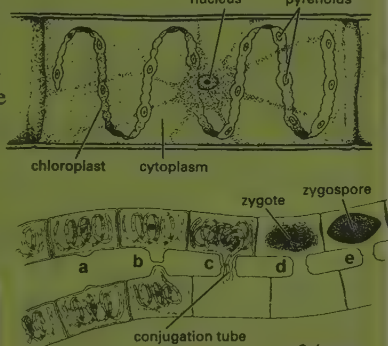
Sexually, *Oedogonium* produces an egg in a specialized cell called an oogonium. Antheridia produce flagellated sperm which swim to enter the oogonium through an opening in the cell wall and fertilize the ovum. The resulting zygote forms a hard protective wall and can remain inactive for several months of unfavorable conditions. Before the zygote wall ruptures, meiosis takes place and 4 flagellate zoospores are formed (a-c).

Oedogonium

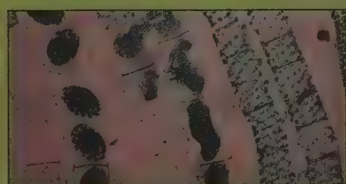


Spirogyra

Named after its unusual spiral-shaped chloroplasts, *Spirogyra* is typical of many filamentous green algae. Usually *Spirogyra,* along with other similar species, is found as floating green mats in ponds or the backwaters of streams. Filaments may reach 0.5 m (20 in.) long. Under proper conditions, *Spirogyra* filaments line up parallel to each other and conjugate (a-e). The cells form a small conjugation tube, and the contents of one cell migrate into the other



Spirogyra



cell. A zygote is formed. A hard, protective wall around the zygote forms a zygospore which is capable of living through unfavorable conditions.

Visual 10B-2 can be used to teach *Spirogyra* characteristics.

Visual 10B-3 can be used as a summary of the characteristics of the various algal phyla. Do not have students copy and memorize the chart. It can be used to point out which characteristics are important enough for the students to know for testing purposes.

Chrysophyta: Chryso- (Gk. KHRUSOS, gold) + -phyta (plant)

Visual 10B-4 can be used to teach *Vaucheria* and diatom characteristics.

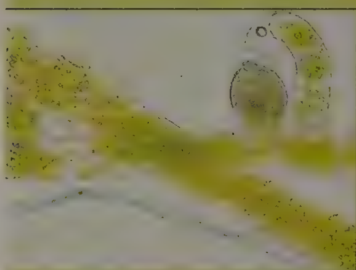
About 270,000 metric tons of diatomaceous earth are annually quarried in California.

Chrysophyta, the Yellow-green Algae and the Diatoms

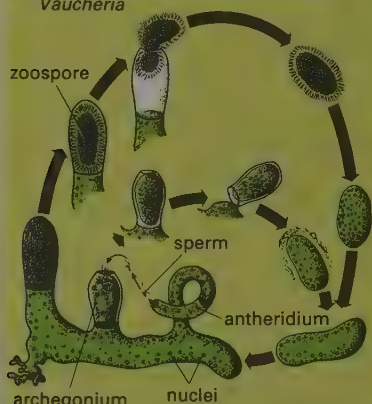
Many algae of the **phylum Chrysophyta*** (krih SAH fuh tuh) are similar to many green algae. The yellow-green algae and diatoms are in a separate phylum because they contain different pigments, store their food as oils, and often have silicon in their cell walls.

Vaucheria

Vaucheria is a filamentous yellow-green algae which is often seen as a thin film on soil, or as mats on the margin of pools and on moist stream banks. The filaments of *Vaucheria* lack dividing cell membranes. They have many nuclei.

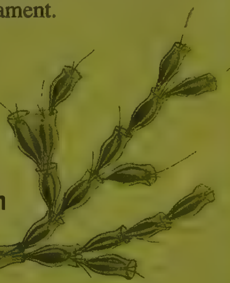


Vaucheria



Asexually, multinucleate zoospores with many flagella are produced on the ends of clublike filaments. Sexual reproduction in *Vaucheria* is by heterogametes produced in specialized structures on the filament.

Dinobryon



Dinobryon is a flagellate alga which often grows in sessile colonies. Some species of *Dinobryon* cause the water to taste fishy and to have a smooth, slimy feel on the tongue.

Diatoms

Diatoms are a group of organisms in the phylum Chrysophyta. Diatoms, in some respects the most important group of algae, are found in abundance in almost every environment on earth. Among the plankton of the open ocean, diatoms are important in the food chain and are responsible for more oxygen-supplying photosynthesis than any other group of organisms. Usually diatoms are unicellular, but some species exist in chains or in other groupings. Diatoms store their food as oil which often appears as large drops in the cell.

The cell walls of diatoms are in two separate halves, one of which fits inside the other. These walls

contain *silica,* an exceptionally hard substance and one of the primary components of glass. These silica walls remain long after the diatom has died.

Large quantities of diatom shells can be found on the ocean floor. *Diatomaceous earth,* a crumbly substance made of diatom shells, is found in many parts of the world. In California some beds of this substance are 900 m (1,394 ft.) thick. Diatomaceous earth is probably the result of diatoms that were deposited during the Flood. It often serves as a filter in industry and in home aquariums. Since it is a poor conductor of heat, it is used to insulate boilers. The shells of diatoms are often the abrasive agent in silver polish and toothpaste.

Although highly protective, the hard cell wall of diatoms presents some problems when the cells are reproducing. Since half of the shell goes with each new daughter cell, some cells become increasingly smaller as cell divisions continue. After several divisions some diatoms shed their cell walls, grow, and then produce new shells. Some diatoms reproduce sexually following several asexual cell divisions.

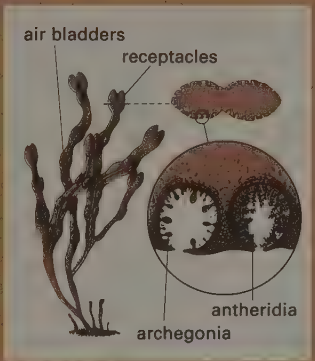
Phaeophyta, the Brown Algae

Species of the **phylum Phaeophyta*** (fay AH fuh tuh) are all multicellular and almost all marine. The brown algae, found in colder waters, usually grow attached to rocks or to the ocean floor. Larger species live in deeper waters, while smaller species thrive along the coast and are often exposed during low tides. Food is stored as a complex carbohydrate. *Algin,* a gelatinous coating found on many brown algae, serves as a thickener in commercially produced ice cream and other foods.

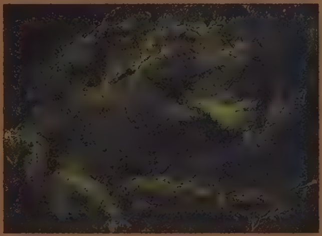
The thallus of a brown alga is usually composed of a holdfast (often an extensive network of cells), a stemlike structure, and leaflike blades. The stemlike structure usually contains *air bladders,* causing the alga to float near the surface. Brown algae produce sperm and ova in multicellular *antheridia* and *oogonia.*

Fucus

Fucus (often called rockweed) is a common shoreline alga. The thick, 30- to 90-cm (1- to 3-ft) leatherlike thallus is not affected by periods of dryness between tides. The swellings at the ends of the thallus are the multicellular reproductive structures.

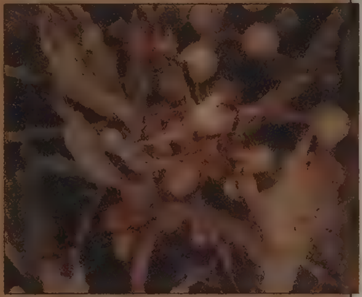


Kelp



The kelps normally grow attached to rocks in water up to 23 m (75 ft.) deep. Some of these large algae may reach 30 m (100 ft.) long.

Sargassum



Sargassum is a genus similar to the kelp but grows in temperate to tropical areas. One species forms floating mats several hundred meters wide in an area of the North Atlantic called the Sargasso Sea.

Phaeophyta: Phaeo- (Gk. PHAIOS, brown) + -phyta (plant)

Rhodophyta: Rhodo- (Gk. RHODON, rose color) + -phyta (plant)

Pyrrophyta: Pyrro- (Gk. PYRRHOS, fiery) + -phyta (plant)

dinoflagellate: dino- (Gk. DINEIN, to whirl) + -flagellate (small whip)

Carrageenan is a gelatinous product of a red algae which is used in dairy products.

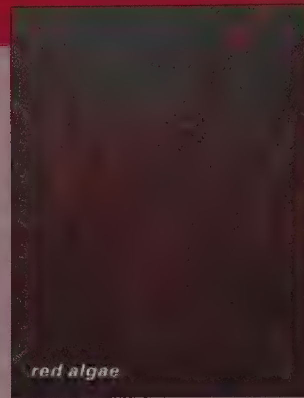
Rhodophyta, the Red Algae

The algae of **phylum Rhodophyta*** (roh DAH fuh tuh) are almost all marine, multicellular, and red. Most red algae grow in shallow, warmer waters, but sometimes they are found at a depth of over 90 m (300 ft.). Some red algae produce ribbonlike thalli, but many are feathery, and others are slender filaments. Almost all red algae are under 30 cm (1 ft.) long. Red algae are unusual in that they produce nonmotile gametes and spores.

Certain red algae draw calcium from seawater and deposit it as calcium carbonate in the gelatinous coat that surrounds them. This calcium carbonate is important in building some reefs and islands. Other red algae products are used in foods. Best known of these is *agar*, a gelatinous substance used in growing bacteria.

Chondrus (Irish moss)

Chondrus is the marine red alga which is the source of agar.



Lemanea

Lemanea is a common freshwater, sessile red alga; its presence indicates clean, flowing water.

Pyrrophyta, the Dinoflagellates

The **phylum Pyrrophyta*** (pye RAH fuh tuh) includes the **dinoflagellates*** (DYE noh FLAJ uh lits). These unicellular algae normally process two flagella of unequal length. One flagellum is normally kept in a groove around the algal cell; the other is used for movement.

The cell walls of the dinoflagellates are made up of multi-sided cellulose plates. Yellowish brown pigments color these algae. Most dinoflagellates are marine, but some species live in fresh water. Some dinoflagellates are bioluminescent (light-producing) and, when the water is disturbed, can emit enough light to cause the sea to glow.

In warm, coastal water certain dinoflagellates *(Gymnodinium brevis* and others) can enter a severe bloom condition called the *red tide*. The abundance of the dinoflagellates during red tides turns vast areas of the sea a reddish brown. These algae secrete a poison which affects the nervous system of fish. Off Florida's Gulf Coast red tides have caused massive fish kills. Smaller quantities of these organisms can pollute shellfish, making them unfit for human consumption.

Gymnodinium brevis

Review questions on page 276.

Red tides are a well-known example of algal blooms (see pp. 275-76). Also see blooms of blue-green algae (p. 233).

Even small amounts of the poison given off by some algae in bloom condition will kill laboratory animals within 15 minutes.

Answers–Review Questions 10B-2 *(p. 276)*

1. Asexual forms of reproduction in algae include unicellular reproduction, fragmentation, and zoospores. Sexual forms of reproduction in algae include conjugation, isogametes, and heterogametes.
2. Zoospores are generally haploid cells which are mobile and can establish new colonies. Zygospores are diploid, the result of the union of gametes; the zygote forms a hard, protective covering for survival in unfavorable conditions. These can undergo meiosis and release zoospores.
3. **(1)** It takes days to build up an algal bloom; the Bible says it happened in the sight of Pharaoh and his servants. **(2)** The blood was in all pools, ponds, and vessels in Egypt; conditions in Egypt would not have caused a simultaneous bloom in the flowing Nile and all the standing water. **(3)** The repetition of the word *blood* indicates that it was indeed blood–not an algal bloom.

Answers–The Algal Phyla

1. Characteristics: **(1)** most freshwater, many terrestrial, and a few marine; **(2)** usually unicellular or in simple colonies; some thalli in marine algae;

❑ *Zoospores* Individual cells in some sessile algae can form specialized cells called **zoospores*** (ZOH uh SPORZ), which have flagella and can swim away and establish new colonies (see *Vaucheria*, page 272; *Ulothrix*, pages 270-71; and *Oedogonium*, page 271).

There are three basic forms of sexual reproduction carried on by algae.

❑ *Conjugation* When two cells that are not obviously specialized as gametes unite, **conjugation** has occurred. This permits the nuclear material from one cell to go into the other. *Spirogyra*, a common pond alga, reproduce by conjugation (see page 271).

❑ *Isogametes* Specialized cells which are not obviously different from one another are **isogametes.** Isogametes fuse together, forming a diploid zygote. *Ulothrix*, a freshwater alga, reproduces using isogametes (see pages 270-71).

❑ *Heterogametes* Specialized cells which differ in either size, structure, or both are **heterogametes.** In some algae, like the *Vaucheria* (see page 272), a nonmotile gamete called an *ovum* (egg) is produced in a specialized structure called the **oogonium*** (OH uh GOH nee um). Sperm, which are the motile gametes, are produced in another structure called the **antheridium** (AN thuh RIHD ee um). Also see *Fucus* on page 273.

Some algae can, under different conditions, form different types of gametes.

Following the union of gametes, the zygote of some algae forms a hard, protective covering and is called a **zygospore.*** Many freshwater algae spend periods of unfavorable conditions (winters or dry seasons) in the zygospore stage. Some algae form zygotes that then carry on meiosis and release motile zoospores (usually 4 haploid cells). The zoospores then swim away and establish new colonies.

Algal blooms

In 1729 Captain W. Dampier, sailing off the coast of Peru, wrote:

> [When] our ship [was] about ten leagues off shore, . . . we were suddenly surprised with the change of the colour of the water, which looked as red as blood to as great a distance as we could see . . . . At first we were mighty surprised . . . . We then drew some water up in buckets and poured some in a glass. It continued to look very red, till about a quarter of an hour after it had been in the glass; when all of the red substance floated to the top, and the water underneath was as clear as usual. The red stuff which floated on top was of a slimy substance, with little knobs, and we all concluded it could be nothing but the spawn of fish.*

Captain Dampier and his crew were probably sailing through an algal **bloom.** A *bloom condition* occurs when all factors affecting growth and reproduction for a particular organism are near optimum. The organisms can then multiply rapidly, resulting in great abundance of new life.

Algal blooms are not unusual occurrences. In the summer, ponds and entire lakes often appear green or blue-green because of blooms of certain algae. Some blue-green algae *(Microcystis, Anabaena)* release a poison. When these algae enter bloom conditions in a farm pond, the livestock can be poisoned by drinking the water.

Unpleasant odors and tastes can occur in city water supplies because of an algal bloom. Algae produce oily substances that cause the "fishy smell" or "marsh odor" associated with certain water supplies. Ill effects of an algal bloom can occur when the algae die. Decomposition and oxygen depletion then foul the water.

Often during a bloom condition, algae color the water with their presence. It is impossible to be sure what caused the red condition described by Captain Dampier. The separating of the water and the "red stuff" and the slimy feel of the substance indicate that it was probably an alga.

Some critics of the Bible have suggested that the first plague of Egypt described in Exodus 7 was a natural algal bloom. Verses 20 and 21 state that "all the waters that were in the river were turned to blood. And the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river."

At first glance it may appear that an algal bloom caused this phenomenon. Other sections of this passage, however, demonstrate that this mir-

The Distribution of Discolored Water, U.S. Navy Hydrographic Office Pilot Chart No. 1401 (Washington, D.C.: Hydrographic Office, January 1955)

zoospore: zoo- (animal) + -spore (seed)

oogonium: oo- (egg) + -gonium (Gk. GONOS, seed)

zygospore: zygo- (yoke) + -spore (seed)

Oscillatoria is pictured on page 233.

The structural terms and methods of reproduction described here are illustrated on pages 271-73.

This is an ideal spot for a discussion of the modernists' interpretation of Scripture. Modernists seek to explain how the ancients were fooled into believing there was a God by "unusual natural happenings." Thus, crossing the Red Sea was done through ankle-deep water, and manna was the droppings of a desert insect. Careful examination of the Scriptural passages which describe miracles reveals that God has placed with the description of what happened some detail which rules out any "natural cause." The drowning of Pharaoh's army in shallow water and all the Israelites' eating insect droppings for more than 40 years require as much supernatural intervention as the belief in the miracle described.

(3) many produce holdfasts and attach to submerged objects; some move by flagella; (4) carry on photosynthesis; (5) contain chlorophyll *a* and *b;* also carotenoids; (6) chloroplast shape is often used to identify a type of algae; (7) food stored as starch around pyrenoids; (8) several means of sexual reproduction. Examples: *Spirogyra, Protococcus, Ulothrix, Oedogonium,* desmids

2. When a cell of *Spirogyra* divides, the filament becomes longer. When a *Protococcus* cell divides, the clump becomes larger. In time the *Protococcus* group will break up because there is no real bond between cells of these colonies.
3. In *Ulothrix* and *Oedogonium*, motile free-swimming gametes are made. In *Spirogyra* conjugation, the contents of one cell unite with another through the conjugation tube. *Ulothrix* produces isogametes (not one male, the other female). Oedogonium produces heterogametes–one small and motile (sperm), the other large and not motile (ovum, egg).
4. Desmids are in phylum Chlorophyta (see description in 1). Most desmids are uni- or bicellular and exhibit symmetry.
5. Characteristics: (1) usually unicellular; (2) food stored as oil in large drops; (3) two halves of cell walls, which contain silica; (4) sexual and asexual reproduction by some (sexual follows asexual division). Examples: *Vaucheria*, diatoms
6. Diatoms, one of the most important groups of algae, have a two-piece, silicon-containing cell wall and store food as oil. Many of them are unicellular, but some form filaments. Diatoms serve as food for small organisms and

acle was not a bloom of microoganisms. The miracle happened "in the sight of Pharaoh, and in the sight of his servants" (v. 20). An algal bloom does not happen instantly; it takes days to build up. Blood was also in all the pools, ponds, and Egyptian vessels (v. 19). Conditions for a bloom in the flowing Nile River would not have caused a simultaneous bloom in the standing water.

Christians must be careful not to attribute miracles to "natural" causes. When the Bible states that God has done a particular thing, we *must* accept His statement. If the water were turned to the *color* of blood, would not God have stated this? The Egyptians, as well as Moses, the human writer of this passage, would have known the difference between blood and alga-polluted, colored water. The repetition of the word "blood" in this passage, as well as in other passages referring to the incident (Ps. 78:44; 105:29), is further evidence that it was blood and not the bloom of some microorganism.

God *can* cause certain "natural" circumstances to work together for His purpose, and He often does so even today. God can also, as is recorded in Scripture, act supernaturally to effect His purpose. These supernatural acts are **miracles.** To try to explain God's miracles by natural circumstances is to deny the power of God.

Biological Terms

plankton	sessile	heterogametes	pyrenoid
zooplankton	thallus (pl., thalli)	oogonium	phylum Chrysophyta
phytoplankton	air bladder	antheridium	phylum Phaeophyta
aquaculture	fragmentation	zygospore	phylum Rhodophyta
indicator organism	zoospore	bloom (bloom condition)	phylum Pyrrophyta
filament	conjugation	miracle	dinoflagellate
holdfast	isogamete	phylum Chlorophyta	

Answers begin on page 274.

Review Questions 10B-2

1. List three types of asexual reproduction common in algae. List three types of sexual reproduction common in algae.
2. What is the difference between a zygospore and a zoospore?
3. List several characteristics of an algal bloom that help make it an unacceptable explanation for the changing of the water into blood in Exodus 7.

The Algal Phyla, pages 270-74

1. List several characteristics and four examples of the phylum Chlorophyta.
2. Compare and contrast asexual reproduction in *Protococcus* and *Spirogyra.*
3. Compare and contrast sexual reproduction of *Ulothrix, Oedogonium,* and *Spirogyra.*
4. Describe desmids.
5. List several characteristics and two examples of the phylum Chrysophyta.
6. Describe diatoms and list several uses of diatoms.
7. List several characteristics and give an example of the phylum Phaeophyta.
8. List several characteristics and give an example of the phylum Rhodophyta.
9. List several characteristics and give an example of the phylum Pyrrophyta.

Thought Questions

1. "Resolved: Algae are the most significant organisms in the world." Prepare a paragraph for the negative position and a paragraph for the affirmative position. Which do you think is the better position?
2. Read the Scriptural accounts of the ravens feeding Elijah, the unfailing meal and oil, and the raising of the widow's son (I Kings 17). What "natural causes" can you imagine (or find in a Bible commentary) that could be used to explain these three miracles? What Biblical evidence supports the position that these miracles were supernatural acts of God and not the result of natural causes?

are major producers of oxygen. Their shells are useful in industry as filters, insulation, and as an abrasive agent.

7. Characteristics: (1) all multicellular; (2) most are marine; (3) found in cooler waters, usually sessile; (4) food stored as complex carbohydrates; (5) algin-gelatin coating; (6) contain air bladders in thallus for floating near surface; (7) produce sperm and ova in multicellular antheridia and oogonia. Examples: *Fucus* (rockweed), kelp, *Sargassum*
8. Characteristics: (1) most are marine; (2) most multicellular and red; (3) usually in shallow, warm waters; (4) most are less than a foot long; (5) produce nonmotile gametes and spores; (6) deposit calcium carbonate (reefs and islands); (7) some supply agar for bacteria cultures. Examples: *Chondrus, Lemanea*
9. Characteristics: (1) unicellular; (2) possess two flagella of unequal length; (3) cell walls of multi-sided cellulose plates; (4) yellow brown pigments present; (5) food usually stored as starches and oils; (6) most marine, some freshwater; (7) some bioluminescent; (8) cause "red tide" bloom condition. Example: dinoflagellates *(Gymnodinium brevis)*

Answers–Thought Questions

1. Answers will vary. Humans, God's special creation, if considered, would be of "more value" as spiritual beings. The inner workings of the rest of the physical creation would indeed be hampered, if not "impossible," without algae. But it would also be hampered, if not "impossible," without bacteria, fungi, plants, birds, etc.
2. Answers will vary.

THE KINGDOM FUNGI

ELEVEN

Time Frame
11 (with Facet): 1-2 periods

Laboratory Activity
11–*The Fungi* should be done in a single period. It is possible to omit the lab and use specimens as visual aids or use some in demonstrations.

The Fungi

Ergot of rye is a fungus which causes a purplish black swelling in rye grain. In the Middle Ages, the disease caused by eating this infected rye was called "St. Anthony's fire." In 944, an epidemic of St. Anthony's fire killed more than 40,000 people. In August 1722 the men and horses of Peter the Great, poised for an invasion of Turkey, consumed rye brought to them by the local serfs. By the following morning, over a hundred horses were paralyzed; about 20,000 people in the area died; and the invasion was effectively stopped.

In 1951, people in a small village in France ate flour ground from infected rye. More than 200 people were made severely ill from the poison; 30 people went temporarily insane, imagining that demons and snakes were chasing them; 4 people died. Interestingly, ergot of rye was the first source for lysergic acid diethylamide (LSD), a hallucinogenic (causing false perceptions or visions) drug. Drugs derived from ergot cause muscles to contract and blood vessels to constrict and have been used to save lives.

LSD; see pages 620-21. Today LSD is produced synthetically.

11–The Kingdom Fungi

The kingdom Fungi has living members that do more than wind up in gravy, soups, and salads. These "lowly" members have a significant place in God's creation. Pointing out the significant place of the fungi is one of the major goals of this chapter.

This subject needs to be treated with a light touch. Stress interesting examples and give just enough basic structures and life cycles for the material to be understandable and significant.

Most fungal structures can be observed easily in preserved specimens or on microscope slides. As long as the number is kept to a minimum, seeing the structures should keep the students' interest. Point out the life cycles of things like wheat rust, mushrooms, and bread mold, and stress significant facts. However, avoid learning the names of various wheat rust spores and whether they are haploid or diploid. Stick with the interesting examples and basic characteristics. In a survey course, details have a place, but that place is not in the kingdom Fungi. Details can easily be passed over without great difficulty and should not appear on a test.

Depending on the time frame and class goals, this chapter may be trimmed significantly. Consider carefully what boxes, Facets, and sections of the chapter the students should read and be accountable for.

11A–The Fungi

Facet

The Facet dealing with edible fungi contains some interesting and odd information about edible fungi. It can easily be read by the students and covered in a few minutes in class.

fungicide: fungi- (L. FUNGUS, fungus) + -cide (L. CAEDERE, to cut or kill)

Infectious diseases caused by fungi are mycoses. Most mycoses affect the skin (ring worm, athlete's foot, jock itch, thrush), but some affect the lungs, oral cavity, and occasionally the meninges. Some kinds of fungal infections which are easily fought by a person's immune system can become significant problems for those suffering from AIDS (more on AIDS, p. 571).

The *late blight fungus of potatoes,* a plant parasite, is an example of the phylum Oomycota. Motile zoospores of this fungus spread rapidly by wind and rain to new areas of the plant and to neighboring plants. The spores of this fungus can germinate in the tubers (potatoes) in the soil, causing them to rot even before they are dug up.

A late blight fungus also affects tomatoes. In 1946 the tomato crop in the eastern United States was cut in half by the late blight fungus, causing an estimated loss of 50 million dollars.

Penicillium roqueforti and *P. camemberti,* species within the same genus as the *P. notatum* (from which comes penicillin), produce the flavors of Roquefort and Camembert cheeses.

Ergot of rye appears to be both bane and blessing. In some respects many fungi are like that. For example, in the early 1800s potatoes were the major crop in Ireland. In 1845, and for several years following, a parasitic fungus, the *late blight of potato*, destroyed virtually the entire crop. Approximately one million people died of starvation between 1845 and 1847. Within 10 yr. the population dropped from 8 million to 4 million. The Irish, however, learned the benefits of diversifying their livelihoods, and many of the Irish in America today are descendants of those who were forced to emigrate during the potato crop failure.

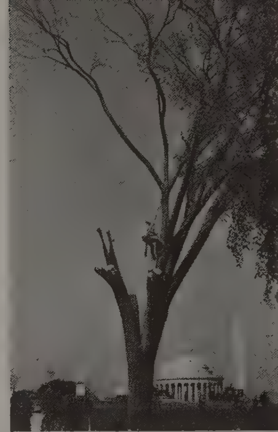
Destructive fungi

Annually, a five-member American family spends over $600 to control and pay for the damage caused by fungi. With the possible exception of the bacteria, the molds of the kingdom Fungi are man's biggest competitors for food. One estimate indicates that plant diseases cost Americans over $3 billion dollars annually. Fortunately, in America, food production far exceeds need.

Some destructive fungi have caused permanent damage by destroying their host species. One of our most important nut and hardwood lumber trees was the American chestnut; however, the *chestnut blight fungus* has eliminated it from American forests. *Dutch elm disease* is caused by a fungus which is spread by the elm bark beetle. The fungus causes the breakdown of the water conduction tissues, and death of the tree is inevitable. Many towns that once had stately elms lining their streets have been forced, in the space of a few years, to remove them. Although scientists are seeking a solution, no prevention or cure yet exists.

11A-1 *Chestnut branch growing from the stump of a once large tree*

Occasionally natural means of preventing fungi distribution can be used. Starting around 1880, a rust fungus caused the coffee trees of Ceylon (now known as Sri Lanka) to lose their leaves. After losing their leaves a few times, the trees died. Tea, which is not affected by that fungus, is now grown in Sri Lanka, and the coffee industry has moved to Brazil. The coffee trees in Brazil could also be affected by the fungus; therefore, Brazillian coffee growers take special measures to insure that their trees are not exposed to it.



11A-2 *The Dutch elm disease, carried by a bark beetle, spreads rapidly, killing American elm trees. These stately trees once lined the streets of many American cities, including Washington, D.C. As the trees became infected, they were removed.*

Other fungi have been controlled by other methods. In the late 1870s, a downy mildew of grapes was accidentally introduced into French vineyards. Within a few years the grape crop was suffering. A professor from the University of Bordeaux noticed that vines growing along the roadside in a certain area did not have this fungus. He learned that the vineyard owners placed a mixture of copper sulfate and lime on the vines. The appearance of this mixture discouraged passersby from stealing the grapes. Scientists at the University of Bordeaux refined and marketed the mixture in 1882. It was the first commercial **fungicide*** for plant diseases.

Beneficial fungi

Most people consider edible mushrooms to be the only beneficial fungi. There are, however, many edible fungi. Many cheeses are the result of fungal growth. Natural Swiss and cheddar, for example, are formed by fungal enzymes working on milk products. The fungi that form Limburger and blue cheese are actually eaten as part of the cheese.

Objectives–Chapter 11

- *❑ List and describe some fungi that are beneficial and others that are both directly and indirectly harmful to man.
- ❑ Describe and give examples of the four major fungi phyla.
- ❑ Describe the methods of sexual and asexual reproduction in fungi.
- ❑ Describe the methods by which fungi obtain food.
- ❑ Define *alternation of hosts* and explain how this has helped to control some plant fungi.
- ❑ Describe the life cycle of a mushroom.
- ❑ Describe the gross anatomy, microanatomy, and symbiotic relationship of lichen.

*From a Facet.

One of the most important fungi is a group of microscopic organisms called the *yeasts*. Many baked goods are leavened by yeasts. Leavening is a substance which produces bubbles of gas in doughs or batters. These bubbles cause the substance to "rise."

Until the advent of other leavening agents and methods of storing yeast in a dormant state, many families kept a lump of dough containing live yeast. This lump, called the leaven, was mixed with a batch of dough. Since yeast grows and divides rapidly, it would serve as the leavening for the whole new batch. A small lump of the new batch would be set aside to serve as the leaven for the next batch of dough.

In the Bible leavening is compared to sin or false doctrine (Matt. 16:6-12; I Cor. 5:6-8). Just as a little leaven will affect the entire lump of dough, so a little error will corrupt the whole man, or even groups of men. Most Bible scholars agree that, in the Old Testament references to sacrifices, leaven often represents sin permeating all men. For the Passover, various other feasts, and most sacrifices, God demanded unleavened bread, similar to a flat, leathery cracker.

Alexander Fleming, a British physician, discovered another useful function of fungi. In 1929, he noted that a ring of dead bacteria formed around a particular fungus growing on his bacterial cultures. The chemical which killed the bacteria was isolated and named penicillin after the common mold *Penicillium notatum,* which formed it. Penicillin was the first antibiotic. Synthetic penicillin is now many times stronger than the substance Fleming extracted, but some penicillin and other antibiotics are still obtained from fungi.

In their most important and most common function, fungi under natural conditions serve as decomposer organisms. Occurring in the soil and other dark, damp places, these fungi break down complex organic substances into simple, soluble forms that plants can use.

Classification of the Fungi

The **kingdom Fungi** contains colonial and unicellular heterotrophic organisms grouped into several phyla. In this chapter are the three most common phyla: Zygomycota, Ascomycota, and Basidiomycota. Fungi are grouped into various phyla by their colonial structure and their methods of sexual reproduction. Lichens (dual organisms composed of both fungi and algae) are usually grouped by their fungal component and are discussed at the end of this chapter.

At one time scientists classified most fungi in the plant kingdom. With few exceptions fungi have cell walls, are sessile, and produce rootlike anchoring structures. Unlike plants, however, fungi lack true tissues and organs. Even large fungi, like mushrooms, are colonial organisms.

Nutrition and respiration of fungi

The primary characteristic that separates the true fungi from both the plant kingdom and the algae is that fungi lack chlorophyll and therefore are heterotrophic. Some fungi are *saprophytes* (feeding on dead material); others are *parasites* (feeding on living material). There are, however, a few fungi that can be either. *Histoplasmosis,* for example, is a human disease caused by a fungus. In the soil this fungus is a saprophytic mold. However, if a man or animal inhales its spores, this fungus can become a parasite; it no longer appears as a mold but exists as individual cells or clumps of cells which reproduce by budding.

Fungi lack specialized structures for digestion. Many parasitic fungi absorb their food in a predigested form; some obtain nutrition directly from the cytoplasm of the host. Most fungi, however, carry on **external digestion.** External digestion requires the secretion of enzymes which digest the food into a soluble form outside the organism. The soluble foods are then absorbed. The enzymes of external digestion are often the harmful substances of parasitic or poisonous fungi.

Most fungi require oxygen for their metabolism, but a few can grow without an abundant supply of free oxygen. Even the fermentation yeasts, however, grow best with at least some free oxygen. All fungi require abundant moisture for active growth, but many species can withstand periods of dryness. To withstand long dry periods, they form spores.

Some fungi are highly specific regarding the pH in which they grow; others are not.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents the diversity of edible fungi and the potential problem of poisonous fungi.

Julius Caesar had tasters who tested his food before he did to prevent him from being poisoned.

Psychological effects of *A. muscaria* include excitation and hallucinations.

In times past, mushrooms were grown in caves. Today they are grown in specially designed buildings or large basements.

Mushroom protein lacks several amino acids. The chitin in fungal cell walls is not easily digested by human enzymes. The vitamin content is so low that it is not listed in most sources.

11A-1 FACETS OF BIOLOGY

Edible Fungi–Delicious or Deadly?

Actually there are many edible fungi. We all eat yeasts in breads, and many eat the blue mold that makes the enzymes that form blue cheese. The morel is highly prized for its delicate flavor. Young puffballs fried in seasoned butter are considered a delicacy.

In Europe, the truffle, a tasty underground fungi, is sought by specially trained dogs or pigs. Dogs, while not as good at finding the fungi, are preferred truffle hunters. You must be alert and always ready to keep the pigs from eating the truffles. Dogs sniff out the fungi, but refuse to eat it.

Bread mold (*Rhizopus*) is not harmful, but most people find it unappetizing. Many of us have eaten bread mold without knowing it. The white hyphae form several days before the obvious dark spores which tell us the bread is moldy.

When you speak of eating fungi, most people think of mushrooms. Today virtually all of the large basidiomycotes which have the "mushroom shape" (and even a few that do not) are commonly called mushrooms. Technically, all mushrooms are edible. The nonedible ones (either because they are tasteless, taste bad, or are poisonous) are toadstools. This, however, is not a good method of classification, since in the same genus are some of the best-tasting mushrooms and some of the most deadly toadstools.

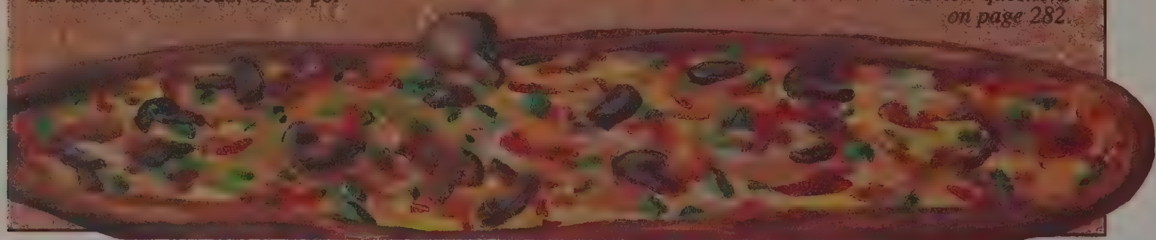
The *Amanita caesarea* (said to be a favorite of Julius Caesar) is, for example, a delicious mushroom while *A. verna* (known as the destroying angel) is one of the most poisonous. This deadly, pure white mushroom causes no symptoms for several hours while the poison enters the tissues. From 6-15 hr. after eating, the person has abdominal pains, vomiting, and diarrhea. Another species, *A. muscaria*, the fly amanita, is fatal in large doses and causes psychological effects in smaller doses. Usually most mushroom collectors avoid all species of *Amanita* to reduce the possibility of getting a poisonous one.

Most people wisely limit their mushroom picking to their grocer's shelves, where they usually find *Quaricus bisporus* (or a similar species) available in any season. They were not collected in a field or forest, but grown in buildings where the temperature and humidity are controlled. Pure cultures of the mushroom fungus are grown in laboratories and are then spread on sterile soil mixed with a rich organic material (horse manure is often used).

After several weeks of growth another layer of soil is spread on the mushroom bed and the mushrooms begin to form. When the buttons emerge, they must be picked quickly because as a mushroom matures it becomes tough and loses its flavor. The bed may be used for a few additional crops of mushrooms, but as the organic material begins to be used up, the whole process must be repeated.

Mushrooms are a true luxury food, but based on their food value, no one should waste time or effort hunting, growing, or buying them. While adding flavor, they add little food value and are not easily digested.

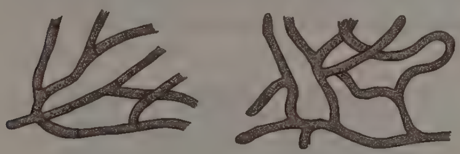
Review questions on page 282.



Cells and colonies of fungi

Most fungi have cell walls composed of *chitin* (KYE tin), a hard but flexible substance. With few exceptions fungi are composed of slender filaments called **hyphae*** (HYE fee). Even large fungi such as mushrooms are merely organized masses of interwoven hyphae.

In some fungal groups the hyphae are *septate;** that is, they are divided into individual cells by cell walls called *septa* (sing., *septum)*. These usually have a hole or pore in them, permitting cytoplasm to pass between the cells of the filament. Some fungi have hyphae which lack septa and are



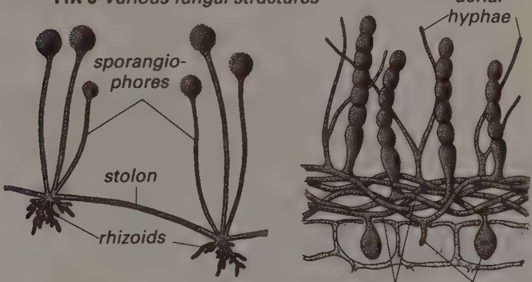
septate hyphae *nonseptate hyphae*

called *nonseptate*. Nonseptate hyphae are typically multinucleate. Although hyphae are only about 5-10 µm wide, some of them may be almost 1 cm long.

Hyphae serve different functions and are often named accordingly:

- **Rhizoids*** (RYE ZOYDZ) are hyphae which are embedded in the material on which the fungus is growing. They serve to support the fungus and digest food.
- **Aerial hyphae** are not embedded in the medium. They absorb oxygen, produce spores, and spread the fungus.

11A-3 *Various fungal structures*



- **Stolons*** (STOH lunz) are aerial hyphae which produce new filaments.
- **Sporophores*** are hyphae branches which produce spores.
- **Haustoria*** (haw STOHR ee uh) are hyphae of parasitic fungi which enter the host's cells to obtain nutrition directly from the cytoplasm.
- **Mycelia** (mye SEE lee uh) (sing., *mycelium)* are masses of intertwined hyphae. A mycelium may be as simple as a clump of bread mold or as highly organized and specialized as a mushroom.

The Imperfect Fungi

Most of the fungal organisms in the phyla Zygomycota, Ascomycota, and Basidiomycota are sometimes grouped together and called the **true fungi,** or *perfect fungi.* A true fungus is one that has a known form of sexual reproduction and can thus be classified. There are, however, a good number of fungi which are not known to reproduce sexually. These fungi are called the **imperfect fungi,** or *fungi imperfecti.*

The list of imperfect fungi was once quite long, and they were given a separate classification. But as scientists cultured and observed them, they were able to see their sexual reproductive structures and were thus able to classify them. Today scientists generally place the imperfect fungi in the phylum Ascomycota since most of them will probably be in this phylum when they can be classified.

Some imperfect fungi are saprophytes, many are plant parasites. A few, however, are parasites of man. *Ringworm* (a small ring of hyphae under the skin), *athlete's foot* (a fungus causing dry, itchy skin near the toes), and *thrush* (a parasite of the mucous membranes of the mouth, nose, and throat) are common imperfect fungi. Fungal infections deep within the body (usually affecting the brain, kidney, or liver) are much rarer but are considerably more serious; they are difficult to treat and may even lead to death.

Reproduction of fungi

Asexual reproduction is the most common type of reproduction in fungi. All fungi can reproduce asexually by stolons or by fragmentation of the hyphae or mycelia, but the most common method is by spores. In formation of *asexual spores*, the sporophore divides from the rest of the hyphae

hyphae: (Gk. HYPHE, web)

septate: (L. SAEPES, hedge)

rhizoid: rhiz- or rad- (Gk. RHIZA, root) + -oid (form or shape)

stolon: (L. STOLO, branch or shoot)

sporophore: sporo- (seed) + -phore (to bear)

haustoria: (L. HAUSTOR, a drainer)

This is a place for dictating terms and definitions. Then discuss several examples.

This box contains supplemental material which should be studied by students. Omit this box if time is limited. This box presents the distinction between perfect and imperfect fungi.

The terms **true fungi** and **imperfect fungi** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Visual 11A-1 may be used as an outline for presenting the classification and examples of the kingdom Fungi.

sporangiophore: spor- (seed) + -angio- (Gk. ANGEION, container) + -phore (to bear)

sporangium: spor- (seed) + -angium (container)

conidiophore: conidio- (Gk. KONIS, dust) + -phore (to bear)

Zygomycota: zygo- (yoke) + mycota (fungus)

by a septum. If the sporophore forms spores within an enclosure, it is a **sporangiophore*** (spuh RAN jee uh FOHR), and the structure in which the spores are formed is a **sporangium*** (spuh RAN jee um). The common bread mold *Rhizopus nigricans* produces sporangiophores and sporangia. The hyphae of bread mold are clear or white. The black appearance of this mold is the result of the colored sporangia and spores.

If the sporophore forms spores by repeated divisions and its spores are not in an enclosure, it is called a **conidiophore*** (kuh NID ee uh FOHR), and the spores are **conidia** (kuh NID ee uh). *Penicillium,* a common fruit mold, produces blue-green conidia from motile, asexual spores.

Sexual reproduction usually does not involve motile gametes, because a fungus mycelium is haploid and sexual reproduction occurs when hyphae of two different mycelia come into contact. In some fungi, as in the bread mold, the resulting diploid zygote forms a *zygospore.* In other species, such as the mushrooms, a new mycelium is formed which contains separate copies of both nuclei (which often remain side by side). The new mycelium grows and becomes the specialized **fruiting body.** The fruiting body of a fungus produces and disperses spores. In the mushroom, the two haploid nuclei fuse, forming a diploid nucleus which then divides by meiosis just before the sexually produced, haploid spores form.

Review Questions 11A-1

1. List several ways in which fungi are (a) harmful and (b) beneficial.
2. What characteristics separate fungi from (a) the plants and (b) the algae?
3. What is the difference between a septate fungus and a nonseptate fungus?
4. Describe five different type of hyphae, based on their functions.
5. Describe asexual reproduction in the fungi.
6. Describe sexual reproduction in the fungi.

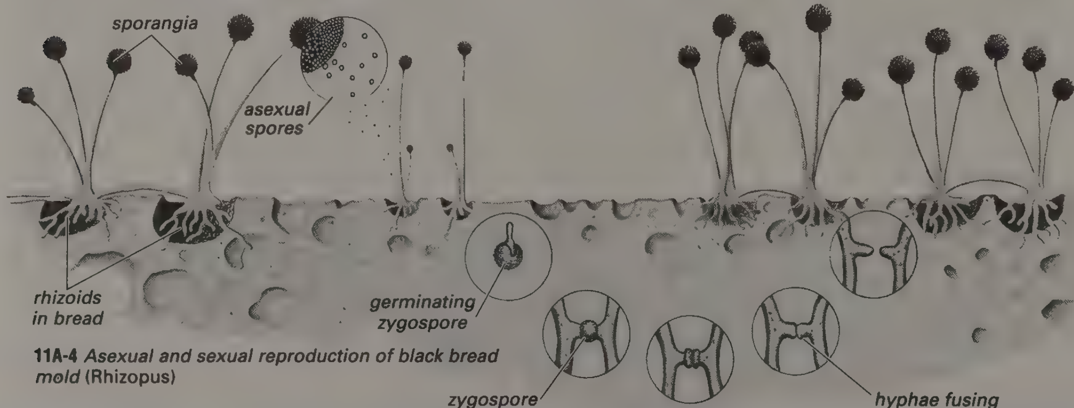
Facet 11A-1: Edible Fungi—Delicious or Deadly? page 280

1. List several fungi people commonly eat.
2. Why is it safe to assume that the mushrooms in grocery stores are not of a poisonous variety that might look similar.

Phylum Zygomycota

Many of the common molds are in the **phylum Zygomycota*** (ZYE goh mye COH tuh). The members of this phylum reproduce sexually by the fusion of hyphae to form a zygote. The zygote often forms a zygospore. Aquatic zygomycotes often produce motile gametes which fuse to form a zygote.

Visual 11A-2 may be used to teach the structures and life cycle of bread mold.



11A-4 *Asexual and sexual reproduction of black bread mold* (Rhizopus)

Answers—Review Questions 11A-1

1. **(a)** Some, such as ergot of rye, can cause disease or even death; as parasites, they cause crop damage in the form of plant blights and other diseases. **(b)** They provide leavening for breads, decompose organisms in the soil and in damp areas, and are a source of food (mushrooms) and medicine (penicillin).
2. **(a)** They lack true tissues and chlorophyll. **(b)** They lack chlorophyll and are completely heterotrophic (saprophytic or parasitic or both).
3. In septate fungi, hyphae are divided into individual cells by walls called septa, which have a pore in them to allow flow of cytoplasm. Nonseptate fungi have no cell walls forming separations; hyphae are usually multinucleate.
4. **(1)** Rhizoids support the fungus and digest food. **(2)** Aerial hyphae absorb oxygen, produce spores, and spread fungus. **(3)** Stolons produce new filaments. **(4)** Sporophores are hyphae which produce spores. **(5)** Haustoria are hyphae of parasitic fungi which enter the host's cells to obtain nutrition from the cytoplasm.
5. Although fungi may reproduce by stolons or fragmentation, the most common method is by spores. The spores form either within an enclosure (sporangiophores in a sporangium) or not in an enclosure (conidiophores producing conidia).
6. Hyphae (haploid) of two different mycelia come in contact, resulting in a diploid zygote. This forms a zygospore or a new mycelium which grows and becomes a highly specialized fruiting body, producing and dispensing spores.

Answers—Facet 11A-1

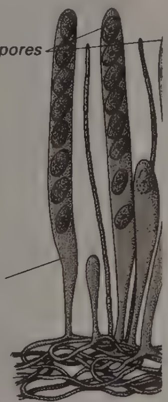
1. Several fungi that people commonly eat are mushrooms, morels, puffballs, truffles, and the molds in certain cheeses (e.g., blue cheese).

The genus *Rhizopus* contains a food mold that is everywhere and familiar to us all, the *black bread mold* (*R. nigricans* or *R. stolonifer*). When the airborne spores of this mold land in a favorable environment, they germinate, forming a small *hypha*. This hypha grows into a *mycelium* with *rhizoids, stolons,* and finally, *sporangiophores* and *sporangia*. Depending on the species, the spores are either black or shades of brown or green. Although baked goods with this mold look unappetizing, they are harmless if eaten. Some molds, however, produce digestive enzymes or other substances which are toxic to humans.

The *downy mildews* (which are similar to the late blight fungus) are named for the soft, fuzzy hyphae often seen on the affected plant parts. Downy mildews cause tremendous damage to crops of cabbage, lettuce, cucumbers, spinach, beans, peas, and grapes.

Phylum Ascomycota

The **phylum Ascomycota*** (AS koh mye COH tuh) are the *sac fungi*, for they form 4 or 8 sexually produced spores called **ascospores*** (AS kuh SPORZ) inside a sac called an **ascus.*** Most ascomycotes have septate hyphae.

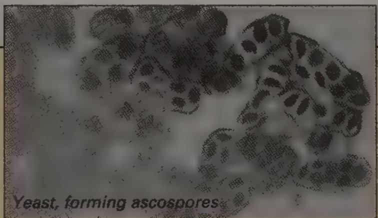


Molds of the genus *Penicillium* (or *Talaromyces*) are typical asco-

Ascomycota: asco- (Gk. ASKOS, bag) + mycota (fungus)

ascospore: asco- (bag) + spore (seed)

ascus: (bag)



Yeast, forming ascospores

The Yeasts

Yeasts are unicellular, predominantly saprophytic fungi found in soil or water. Some yeasts are highly specific (for example, existing only under pine trees), while others live in a wide variety of habitats. A few yeasts are parasites, and a few cause human diseases. The approximately 350 yeast species are in phylum Ascomycota.

Yeasts are typically egg-shaped cells, slightly larger than bacteria. Yeast cells usually have a single vacuole containing stored substances and enzymes. Each cell has a cell wall which becomes thicker and more rigid with age. Some yeasts produce and store large quantities of fat, carbohydrates, or protein and have been grown to supply these materials for human consumption. Yeasts also produce vitamins B and D, especially B_2 (riboflavin). Some people eat yeast or ground yeast products to obtain these vitamins. Yeasts are also grown commercially to produce enzymes used in the manufacture of syrup, cheese, soft-center candies, and medicine.

Yeasts reproduce asexually by **budding.** Near the edge of the cell, the nucleus divides by mitosis. A swelling of the plasma membrane and the cell wall produces a small pouch, and one of the new nuclei moves into it, forming a *bud*. Attached to the parent cell, the bud continues to grow until it is about the same size. The cell wall and membrane between the two has formed by then, and the cells may separate. Often, however, they remain attached. Additional budding can form random-shaped chains.

During periods of unfavorable conditions, yeast cells can form spores, which can remain dormant for long periods. Active dry yeasts contain the living spores of *baker's yeast* for use in home baking.

Most yeasts grow with oxygen, but many can reduce their metabolic rates and carry on fermentation processes. These fermentation processes account for the leavening action of baker's yeasts and the alcoholic production of *brewer's yeast* (in beer) and *wine yeasts.* Baker's yeasts remain active in only relatively mild alcoholic concentrations (about 4%). They soon die or form spores if favorable aerobic conditions are not restored. In baked goods the heat of baking stops the fermentation process and evaporates the alcohol. Some of the yeasts used in the manufacture of beers and wines can tolerate alcohol concentrations of about 12%. Liquors with a higher alcohol concentration are obtained by distillation (removing water).

This box contains supplemental material which should be studied by most students. Omit this box if time is limited. The box presents the structure of yeasts and a brief presentation of their diversity.

The terms **yeast** and **budding** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

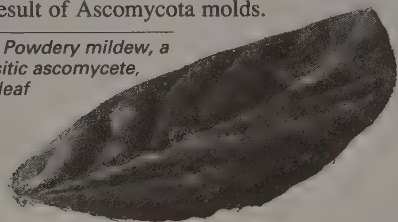
2. Commercial mushrooms are grown in special areas rather than collected from the wild.

basidiospore: basi- or basidio- (L. BASIS, base) + spore (seed)

basidium: (base)

mycetes. These molds form white mycelia which you can easily observe on the rinds of oranges and on other fruits and foodstuffs. Asexual reproduction is accomplished by *conidia*. Other species in this genus produce the flavors of Roquefort (blue cheese), Camembert, and other cheeses.

Ascomycota molds include the genera *Aspergillus* and *Neurospora* (the red bread mold). A number of serious plant diseases such as ergot of rye, chestnut blight, and Dutch elm disease are the result of Ascomycota molds.



11A-5 *Powdery mildew, a parasitic ascomycete, on a leaf*

The *powdery mildews* are named for the cobwebby mycelia which they form over the leaves of young stems of lilacs, grapes, roses, apples, squash, and other plants. These mildews obtain food from the living plant cells by haustoria. Although powdery mildews usually do not kill the plant, they reduce the size of the plant and the crop, and they often weaken the plant so that it can be easily killed by other factors.

11A-6 *Ascospores are produced inside the spongy-looking top of the edible morel (left) and inside the cup of the cup fungus (right).*

Many ascomycotes, such as the delicately flavored *morel*, form extensive fruiting bodies to release their spores. The *cup fungi* are ascomycotes that form saucer- or bowl-shaped fruiting bodies. Their cups may be 1-10 mm in diameter. Usually saprophytic, the cup fungi grow on the forest floor or on dead wood. Spores are dispersed primarily as falling drops of water splash them out of the cups. Other cup fungi fling their spores into the air.

Phylum Basidiomycota

The **phylum Basidiomycota** (buh SID ee oh mye COH tuh) are called the *club fungi* because they form four sexually produced **basidiospores*** (buh SID ee oh SPORZ) on a club-shaped cell called a **basidium*** (buh SID ee um). This phylum contains the *mushrooms* and similar fungi, *puffballs* and *earthstars, shelf fungi* (bracket fungi), *rusts,* and *smuts*.

Mushrooms are usually saprophytic fungi. The well-known but short-lived **cap** and **stipe** (stalk) are only the *fruiting body* of an extensive underground network of hyphae, which may cover several square meters of soil and may be several decades old. When the humidity and temperature are right, the hyphae stop growing and "regroup" stored substances into one or several tiny knobs near the surface of the soil. These knobs are actually twisted networks of hyphae (mycelia) which take on the shape of a compressed miniature mushroom. Once the structures form within their thin covering membranes, the knobs are called the *button stage* of the mushroom.

The **gills** have thousands of *basidia,* each of which produces four *basidiospores*. The basidiospores are shot from the basidium and then fall between the gills onto the soil. If the gills were not lined up properly, the spores would fall on the gills and not be dispersed. Some mushrooms have pores rather than gills under their caps.

Wind and water carry the spores to other areas. A good-sized mushroom may produce billions of spores, but few of them will ever become mushrooms. Even after the short-lived fruiting body has withered, the hyphae may live on to produce other mushrooms in future years.

Puffballs and *earthstars* produce their spores within protective membranes. Mature puffballs release their dust-fine spores as they are disturbed. The outer membrane of the earthstar folds back

Rusts and Smuts: Plant Parasites

In the phylum Basidiomycota are several very harmful plant pathogens including the **rusts** and **smuts.** The *rusts* usually have complicated life cycles producing several different kinds of spores and alternating between two different plant hosts.

Wheat rust, for example, causes dark, rust-colored patches on the stems of wheat and other grains. These patches produce red *urediospores* (yoo REE dee uh SPORZ) which can be carried by wind and water to infect other wheat plants generally during the same growing season. At the end of the season, the plant begins to yellow, and the hyphae produce *teliospores* (TEE lee uh SPORZ). Teliospores can live through the winter and then germinate to form *basidia* and *basidiospores.* The basidiospores, however, cannot directly infect wheat. They infect the barberry, and on the underside of the barberry leaves this fungus forms tiny cups in which *aeciospores* (EE see uh SPORZ) are produced. These aeciospores infect wheat and cause the rust-colored spores. The *alternate host* (in this case, the barberry) is essential for a rust to complete its life cycle.

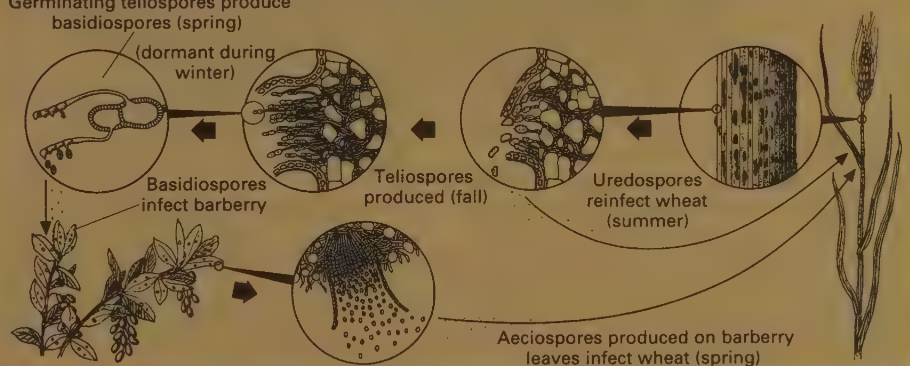
In colonial Massachusetts a law was passed ordering the destruction of all barberry bushes. It was believed that eliminating the barberry would eliminate the wheat rust; indeed, this action did achieve a measure of control. However, a barberry bush can supply aeciospores to infect a wheat field hundreds of miles away. Today wheat rust is controlled by breeding resistant varieties of wheat, as well as by controlling the number of barberry bushes. Other significant rusts in the United States include the *apple cedar rust* and the *white pine blister rust.*

Corn smut

The *smuts,* like the rusts, produce several different spores in their life cycle, but they usually do not have an alternate host. Smuts infect grains such as wheat, barley, rye, oats, and corn, causing enlargement and filling them with sooty spores. Smuts cause hundreds of millions of dollars worth of damage to crops each year. *Corn smut* survives the winter as spores in the soil. Scientists are seeking to develop smut-resistant varieties of corn.

Wheat rust on barberry (right) and wheat (left)

Wheat Rust Life Cycle



This box contains supplemental material which should be studied by most students. Omit this box if time is limited. The box presents the significance of some of the harmful plant parasites.

The terms **rust** and **smut** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Students should not be expected to learn the names of all the spores in the life cycle of wheat rust. Note its life cycle and the fact that it alternates hosts.

Uredospores from southern-grown wheat can be carried by the wind to infect northern wheat when the northern winters are not harsh enough to destroy them.

symbiosis: sym- (together) + -biosis (life)

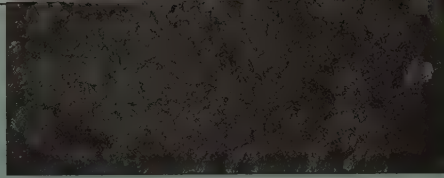
This box is supplemental but contains information common in biology texts which should be studied by most students. Omit this box if time is limited.

The terms **lichen, symbiosis, crustose, foliose, fruticose,** and **soredia** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Visual 11A-3 may be used to teach about the structures and life cycle of mushrooms.

The pressure exerted by mushrooms (and other fungi) as they mature is significant. They have been known to crack several inches of asphalt and have been credited with enough pressure to move large pieces of sidewalk.

The longevity of the hyphae, along with their saprophytic nature, is illustrated by fairy rings. As old areas are depleted of food, the hyphae grow farther from their point of origin to obtain new sources. In time, the hyphae in the center die, but the ring of living hyphae continues to grow. This ring of hyphae produces mushrooms in a circle, called a fairy ring. Fairy rings may be only a few centimeters across, but some are over 6 m (20 ft.) in diameter and produce mushrooms annually in an ever-widening circle.



Lichens

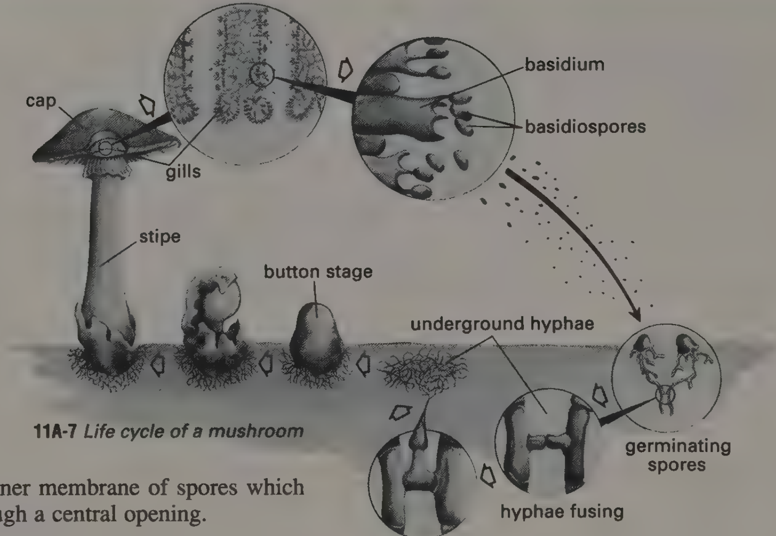
Some of the most unusual organisms are not single, but dual organisms: the **lichens** (LYE kunz). Often found in the harshest environments, the two organisms in a lichen work together to maintain life. Thus many of them can grow in places such as bare sunny rocks and roof shingles, where no known single living thing could survive.

Although most familiar lichens are common on tree bark, fence posts, and brick walls, some of the largest patches of lichen are in the tundra. *Reindeer moss,* an important food source for caribou and reindeer, can be found in mats several centimeters thick and several kilometers wide.

A lichen consists of a fungus and an alga living together. The relationship of two organisms living together is called **symbiosis*** (SIM bye OH sis). In lichen symbiosis the alga captures sunlight and manufactures sugars for itself and the fungus; the fungus supports and protects the alga.

Most lichens can dry out, losing over 30% of their water, and spend many months with an extremely low metabolism. When moisture returns, the lichens quickly absorb water, and full metabolism resumes. Many grow slowly, increasing their radii less than 1 mm per year. Some patches of lichen appear to be over 100 yr. old.

Scientists place the approximately 16,000 lichen species in three categories, based on their appearance.



11A-7 *Life cycle of a mushroom*

and reveals an inner membrane of spores which are released through a central opening.

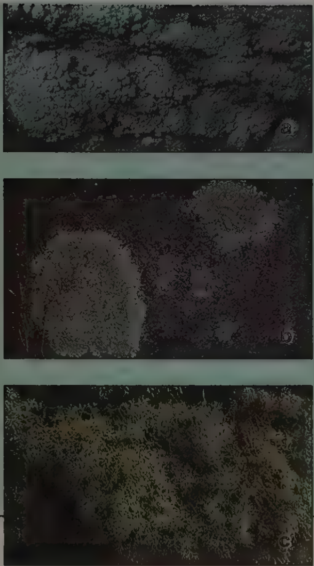
The **gills** have thousands of *basidia*, each of which produces four *basidiospores*. The basidiospores are shot from the basidium and then fall between the gills onto the soil. If the gills were not lined up properly, the spores would fall on the gills and not be dispersed. Some mushrooms have pores rather than gills under their caps.

Wind and water carry the spores to other areas. A good-sized mushroom may produce billions of spores, but few of them will ever become mushrooms. Even after the short-lived fruiting body has withered, the hyphae may live on to produce other mushrooms in future years.

Answers–Review Questions 11A-2

1. **(a)** Phylum Zygomycota–reproduce sexually by various forms of conjugation; zygospores often form; aquatic phycomycetes often produce motile gametes (e.g., *Rhizopus* [bread molds], downy mildews); **(b)** Phylum Ascomycota–"sac fungi" form 4 to 8 spores called ascospores inside a sac called an ascus (e.g., *Penicillium, Aspergillus, Neurospora*, powdery mildews, most yeast); **(c)** Phylum Basidiomycota–hyphae usually septate; often produces large fruiting bodies; spores produced on a basidium (e.g., mushrooms, puffballs, shelf fungi, rusts, smuts, earthstars)
2. Yeasts are unicellular, egg-shaped cells, slightly larger than bacteria. They have a single vacuole with stored substances and enzymes. The cell wall becomes thicker and more rigid with age.
3. A fungus which is not known to have a form of sexual reproduction is an imperfect fungus. When sexual reproduction of the fungus is observed, it can be classified in its proper phylum.
4. (See p. 285.) **(1)** Uredospores infect other wheat plants. **(2)** Teliospores can live through winter and germinate to form basidia and basidiospores but cannot directly infect wheat. **(3)** Basidiospores infect barberry on the underside of leaves and form aeciospores. **(4)** Aeciospores infect wheat and cause rust-colored spots.

*5. A lichen consists of a fungus (usually Ascomycota) and an alga (usually Chlorophyta, sometimes Cyanophyta) which exist together (symbiosis) and are dependent on each other in their relationship (mutualism). The alga produces food (photosynthetic), and the fungus supports the alga. Three types exist: crustose (flat or nearly flat), foliose (leaflike), and fruticose (shrubby,



❑ **Crustose*** (KRUS TOSE) (crustlike) lichens appear as flat smears of dried paint (a).
❑ **Foliose*** (FOH lee OSE) (leaflike) lichens look like small, crinkly leaves (b).
❑ **Fruticose*** (FROO tih KOSE) (shrubby) lichens have stalks or branches often with conspicuous fruiting bodies on their ends (c).

All the algae in lichens can live independently, but the fungi of lichens are not found by themselves in nature. The fungus produces spores, but when these spores germinate they must quickly contact an alga and parasitize it. This method of lichen reproduction has been demonstrated with great difficulty in the laboratory.

Most lichens reproduce by releasing dustlike pieces of lichen called **soredia** (suh REE dee uh) (sing., *soredium*). A soredium contains both the alga and fungus but not in a protective case. Thus, soredia must be transferred to a place suitable for lichen growth. Birds and crawling animals are responsible for spreading lichen soredia.

Although lichens are able to withstand some of the harshest of natural conditions, they are extremely sensitive to air pollution. Since lichens absorb and concentrate materials from rainwater and air, they stop growing and die if the air contains too much of certain substances. The growth of lichens can indicate air quality. In many industrial cities lichens have died, but farther away from such places lichens grow abundantly.

crustose: crust- (L. CRUSTA, crust) + -ose (L. -OSUS, full of)

foliose: foli- (L. FOLIUM, leaf) + -ose (full of)

fruticose: fruti- (L. FRUTEX, shrub or bush) + -ose (full of)

The symbiosis of a lichen is called mutualism because both organisms benefit and neither is harmed. See pages 466-67 for other examples of symbiosis and of mutualism.

The lichen fungus is usually of the phylum Ascomycota, and the algae is either of the phylum Chlorophyta or Cyanophyta. The lichen algae can and do exist alone. The fungus really depends upon the alga. Under certain conditions the fungus may kill the alga and then die itself. Although the fungi of lichens have been cultured independently of lichens in laboratories, if it were not for the algae and lichen relationship, these fungi would perish.

Lichens are often among the pioneer organisms in succession on a bare rock because they can tolerate the extremes of heat and cold, wet and dry found on bare rock, and the fungus needs only the tiniest of cracks to insert hyphae.

One of the early warnings of acid rain falling in an area is the death and disappearance of lichens.

Biological Terms

The Kingdom Fungi

fungicide	true fungi	yeast	gill
kingdom Fungi	imperfect fungi	budding	crustose
external digestion	sporangiophore	phylum Basidiomycota	foliose
hyphae, (sing., hypha)	sporangium, (pl., sporangia)	basidiospore	fruticose
rhizoid	conidiophore	basidium, (pl., basidia)	soredia, (sing., soredium)
aerial hyphae	conidia	cap	
stolon	fruiting body	stipe	
sporophore	phylum Zygomycota	rust	
haustoria	phylum Ascomycota	smut	
mycelia, (sing., mycelium)	ascospore	lichen	
	ascus	symbiosis	

Review Questions 11A-2

1. Give characteristics and list three examples of each of these phyla: (a) Zygomycota, (b) Ascomycota, and (c) Basidiomycota.
2. Describe the structure of a yeast.
3. What is an imperfect fungus, and why is the list of imperfect fungi growing shorter?
4. List and give the functions of the four types of spores produced by wheat rust.
5. Describe a lichen.
6. List the three basic forms of lichens and describe each.
7. Lichens are often called "pioneer organisms." What characteristics of lichens permit them to serve as pioneer organisms?
8. Describe the structure and the life cycle of a mushroom.

Thought Question

Many fungi grow in a ring shape. Why is this typical of fungi?

having stalks or branches often with conspicuous fruiting bodies).

*6. Lichens are normally grouped as crustose (crustlike), foliose (leaflike), or fruticose (shrublike).

*7. Lichens may be called "pioneer organisms" because they are able to thrive in areas, such as rocks, where other organisms are unable to survive. The growth of lichens gradually breaks down rocks and hard soil, providing a medium for growth of other organisms.

8. The structure consists of the cap and stipe, which form the fruiting body, and the underground network of hyphae. The basidia, which produce basidiospores, are located underneath the cap. **(1)** Certain conditions of warmth and moisture stimulate growing hyphae to stop and regroup stored substances into one or more tiny knobs near the soil surface. **(2)** Once structures form within thin covering membranes, the mushroom is in the button stage. **(3)** Cells of mycelia fill quickly with water. **(4)** The stalk and cap exert pressure as they grow toward light; the cap adjusts itself so that the gills are vertical underneath. **(5)** Gills produce basidiospores within basidia. **(6)** Basidiospores are forcefully flung from basidia and fall between gills and onto soil. **(7)** Wind and water carry spores to other areas, and new mushrooms form. **(8)** Hyphae continue to grow and reproduce in future years.

*From a box.

Answer–Thought Question

As the new hyphae grow out from the center, they utilize nutrients in their immediate environment. The sporangiophores develop, form and release spores, and then the hyphae die. New hyphae on the periphery of the mycelium continue to grow out as spore formation continues.

botany: (Gk. BOTANE, herb or plant)

The Plant Kingdom and Plant Structure
Botany Part I

Twelve

Time Frame
12A: 1-2 periods
12B (with Facet): 2-3 periods

Laboratory Activities
12A–*Plant Identification* is a profitable laboratory exercise if done properly. It will take a few minutes of explanation and examples the day before the exercise is done. The exercise itself can be done in 20 minutes to an hour.

12B–*Plant Organs* can be used to reinforce the structures discussed in Chapter 12B. The exercise should take less than a period.

12A-Plant Classification

Botany,* the study of plants, may not top your list of interesting subjects. ''After all,'' you may say, ''plants are all alike. They are green things that just sit there.'' If you think this way, you obviously have only a passing acquaintance with these ''green things.''

First of all, not all green things are plants. Fungi can contain green pigments. Algae, protozoans, and even some bacteria may contain enough chlorophyll to make them green. These tissueless organisms, once classified in various phyla of the plant kingdom, are now usually placed into other kingdoms because the presence of tissues is a plant kingdom characteristic.

Second, not all plants are green. Some have other pigments which mask the green chlorophyll. Although most plants carry on photosynthesis with chlorophyll localized in plastids (autotrophic), there are thousands of *heterotrophic plants.*

Third, we cannot overestimate the value of plants to man. The plant kingdom provides almost all our food. Cereals such as corn, wheat, and

12–Botany Part I: The Plant Kingdom and Plant Structure

Botany is a big subject. Most of its major topics are discussed in Chapters 12 and 13 of this text, but many of them are merely mentioned in passing. The real plant lover will be tempted to go into a deeper study of the plant kingdom than is presented here. For a survey course, however, it is not wise to add much to the material in the text.

On the other hand, many teachers regard the study of plants as necessary but definitely uninteresting. This feeling is too often relayed to the students. A teacher cannot instill more interest in a particular subject than he has. This probably explains more classroom failures than any other single cause. For those who lack the necessary interest, consider a paraphrase from Shakespeare: assume an interest where you have it not.

This chapter begins with a discussion of the various kinds and groups of plants and the reproductive cycles of the mosses, ferns, and gymnosperms. It then progresses to a discussion of basic plant anatomy (leaves, roots, and stems). Chapter 13 deals with plant physiology and progresses to flowering plant reproduction.

Because of the different kinds of material that make up the study of botany, different teaching techniques should be employed. With a little planning the teacher should be able to secure abundant specimens for classroom teaching of botany even in the dead of winter. The produce department of the grocery, classroom potted plants, a friend's potted plants, cuttings taken from landscape plantings, a florist, and a few preserved specimens should supply all the plant material needed.

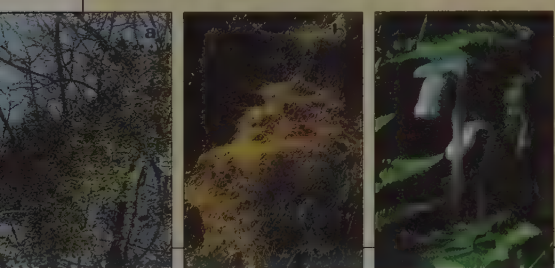
rice, along with legumes such as peas, beans, and soybeans, are our primary food sources. We also consume many other fruits and vegetables directly. Even spices, honey, coffee, tea, cocoa, and juices are derived from plants.

Although scientists believe that most photosynthesis-produced oxygen comes from algae, plants contribute a share of this life-supporting gas. Plant products include paper, gum, wax, alcohol, turpentine, cork, lumber, cloth fibers, coal, petroleum, medicines ranging from castor oil to codeine, and cellulose to be made into plastics.

Finally, plants are a source of inestimable beauty. The quiet stateliness of a lush forest and the delicate simplicity of a pale flower are not byproducts of God's creation. They are as much a part of His plan as the "useful" aspects of the kingdom Plantae.

Heterotrophic Plants

a Mistletoe is a partially parasitic plant. It contains chlorophyll, and although it gets water and minerals from the host tree, it obtains little food from the tree.
b Dodder, however, has so little chlorophyll that the entire plant appears yellowish orange. Since few of its pigments are capable of photosynthesis, the dodder obtains almost all its food by rootlike structures which penetrate the stems of a host plant.
c Indian pipes, however, are completely saprophytic. Containing no chlorophyll or other pigments, these plants appear a ghostly white. They are believed to absorb food made soluble by certain fungi growing in association with their roots. You may wonder why Indian pipes and similar plants are not classified as fungi. Simply, they contain tissues and produce flowers, fruits, and seeds.



The kingdom Plantae

Botanists have divided the **kingdom Plantae** into nine phyla (often called "divisions"). We will group these phyla into three groups based on the presence or absence of **vascular* tissues** and **seeds.** Vascular tissues are specialized structures that conduct water and dissolved materials in a plant. A seed is a structure that contains a young plant and stored food in protective seed coat.

The Main Groupings of Plant Phyla

❑ **Non-vascular plants** Only one phylum of plants lacks vascular tissues: Bryophyta. In this group are the mosses and similar plants.
❑ **Vascular plants without seeds** Four phyla of plants have vascular tissues but lack seeds. The best known phylum is Pterophyta, the ferns.
❑ **Vascular plants with seeds** This group is usually divided into the following two subgroups:
- Non-flowering plants, the *gymnosperms* (four phyla, the best known is Coniferophyta, the cone bearing plants);
- Flowering plants, the *angiosperms* (one phylum, Anthophyta).

Non-Vascular Plants – The Mosses

Non-vascular plants are in **phylum Bryophyta*** (brye AH fuh tuh) which contains the mosses, liverworts, and a few similar groups. People are prone to call any small green thing a moss, even though it could be grass, fungus, or anything else. Common names for many organisms are misleading. Irish moss is an alga. Reindeer moss is a lichen. Spanish moss is a flowering plant. Club mosses, even though they may look like large true mosses, have vascular tissues and are therefore not bryophytes.

In tropical areas the abundant mosses can give a tree trunk the appearance of being several times its diameter. They are often the dominant vegetation in vast areas of tundra, where they must live for months under ice and snow. Most mosses growing in temperate regions appear as velvety clumps in shaded areas or as delicate green carpets covering rocks or logs near streams, waterfalls, or other sources of moisture.

vascular (L. VASCULUM, vessel)

Bryophyta: bryo- (Gk. BRYON, moss) + -phyta (plant)

Be sure to have students read and cover in class the *Main Groupings of Plant Phyla* box if they will be learning the classifications of plants. It is suggested they be responsible for the four phyla named in the Biological Terms section in the back of the chapter and the two flowering plant classes (monocots and dicots). Consider adding others.

The *Heterotrophic Plants* box is supplemental but contains material that most students should be familiar with. Consider having students read the box, and then cover its content briefly when describing the plant kingdom characteristics.

There are no terms in the Biological Terms section from this box. The box presents that not all plants are autotrophic.

Visual 12A-1 is designed to serve as an outline for presentation or review of Chapter 12A. It can be used to inform students what classifications and what characteristics they will need to know for testing purposes. (Consider showing the visual and then marking the items the students are to know or crossing off the ones they are not expected to know.) Point out to the students that the information on the visual is essentially the same as the information in Appendix B (pp. 655-57), ▶

12A–Plant Classification

Notes–Chapter 12A

Chapter 12A is a brief survey of the groups in the kingdom Plantae. As the groups are presented, the life cycles of mosses, ferns, and pine trees are discussed. The reproduction of anthophytes (angiosperms) is covered in Chapter 13B.

Those who are familiar with the previous editions of this text or who learned their botany "a while back" will find the classification of the kingdom Plantae a bit different in this book. Several of the subphyla and classes have been changed to phyla. The groupings are basically the same and frequently have the same prefix in the group's new name. Although some of the old classifications are now obsolete, they will continue to be used for a while because they are so common. The classifications used in this chapter represent the generally accepted changes in plant taxonomy which are widely used at this time.

Objectives–Chapter 12A

❑ Describe the structure and life cycle of a moss.
❑ Describe the structure and life cycle of a fern.
❑ Describe the life cycle of a pine tree.
❑ Describe the life cycle of a flowering plant.
❑ Distinguish between monocots and dicots, using several characteristics.
❑ List characteristics and examples of the following taxonomic divisions: Bryophyta, Lycophyta, Pterophyta, Coniferophyta, Ginkgophyta, Anthophyta, Monocotyledonae, Dicotyledonae.

gametophyte: gameto- (marriage) + -phyte (plant); *hence,* the plant that produces the next generation of its kind

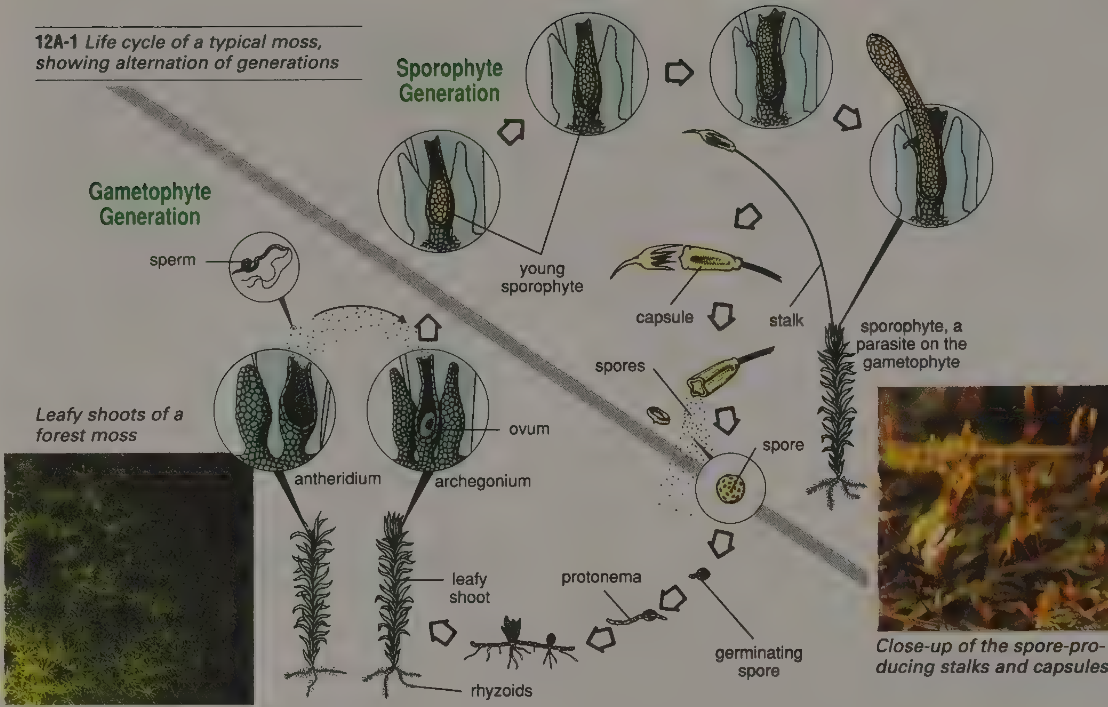
▶ and they need not copy it. Notes from the lecture should be sufficient.

It is acceptable to scan or omit the life cycle of the moss. This would greatly reduce the materials the students would be held accountable for regarding Bryophyta. If omitting this section, it is suggested that the fern life cycle be omitted as well. If covering only one, choose the fern life cycle and the alternation of generations from the moss life cycle. The concept of alternation of generations often appears on standardized tests. Use this diagram to trace the life cycle of moss. Slides of various mosses can illustrate the diversity of structures. Dried or preserved specimens collected in the woods can be useful in the classroom.

In some tropical species the leafy shoot may exceed 0.6 m (2 ft.) in length.

Visual 12A-2 can be used to teach about the life cycle of a typical moss. It points out alternation of generations and the various structures presented in the text. Consider using colored transparencies and pens to enhance the visual.

12A-1 *Life cycle of a typical moss, showing alternation of generations*



Leafy shoots of a forest moss

Close-up of the spore-producing stalks and capsules

In a clump of moss there actually are many densely packed individual plants. The most obvious part of a moss, called the **leafy shoot,** is generally less than 3 cm (1 in.) long and transmits water in small spaces between the cells in much the same way that a paper towel absorbs water. Each of the leaflike structures of a moss is one cell layer thick, except near the center where extra support is needed. Leafy shoots of various mosses may appear vastly different.

On the bottom of each shoot is a tangled mass of rhizoids. **Rhizoids** may appear rootlike, but they lack conducting tissues and therefore are not true roots. Moss rhizoids are usually filaments of cells used for anchorage. Many mosses lack the protective waxy *cuticle* found on most plant leaves. Mosses can therefore absorb water and minerals directly through the leafy shoot, but they can also dry out more readily than most plants. They thrive in moist environments.

Life cycle of a moss

The leafy shoot is only one stage in the life cycle of a moss. There are two different types of leafy shoots: the tip of one has the male reproductive structures; the other has the female structures. Usually these structures are on different plants, but occasionally they are on different branches of the same plant. Since the leafy shoot produces the gametes, this stage in the life cycle is called the **gametophyte*** (guh MEE tuh FITE). The top of a male gametophyte bears saclike **antheridia.** Spiral-shaped sperm are produced inside these sacs. The top of a female gametophyte has one or more vase-shaped **archegonia** (AR kih GOH nee uh). Each archegonium contains an ovum (egg cell) at the bottom of a slender neck. The neck of the archegonium is closed until the ovum is ready to be fertilized.

When water touches the top of the antheridium, the sperm are released. When the water also

In this chapter it is helpful to show slides of examples of the taxonomic groups from the local area as well as interesting varieties from afar. Each slide should illustrate characteristics that the students should be familiar with. By showing examples of the material they should know, their horizons are broadened, and the material previously covered is reinforced and reviewed.

A herbarium of personally collected specimens and a few living specimens found during a class outing in the woods can add interest.

touches the top of a female plant, an open archegonium releases a chemical which stimulates the flagellated sperm to swim toward the ovum. Water and clustering of the gametophytes are essential for fertilization of bryophytes, since the sperm must swim from the antheridia to the ovum.

The fertilized ovum (zygote) grows into a stalk with a capsule on the top. Since this structure produces spores in the capsule, it is called the **sporophyte.*** The sporophyte is the result of the union of two gametes and is therefore diploid. The sporophyte begins as a parasite on the gametophyte. Some never contain enough chlorophyll to support themselves and constantly depend upon the leafy shoot.

The capsules and stalks are often brown, red, or orange. When mature, the cap comes off the capsule, and the wind distributes the released spores. When environmental conditions are suitable, the spore begins to grow. First it produces a cellular filament called a **protonema*** (PRO tuh NEE muh). The protonema then forms the leafy shoots and rhizoids of the gametophyte to complete the cycle.

Botanists call the type of life cycle illustrated by the mosses **alternation of generations.** The gametophyte gives rise to the sporophyte generation, and the spores give rise to the next gametophyte. Spores cannot produce sporophyte stalks and capsules, nor can zygotes produce gametophyte leafy shoots. The two generations must alternate. Because the gametophyte generation is the stage more often seen, in bryophytes it is called the **dominant generation.**

sporophyte: sporo- (seed) + -phyte (plant)

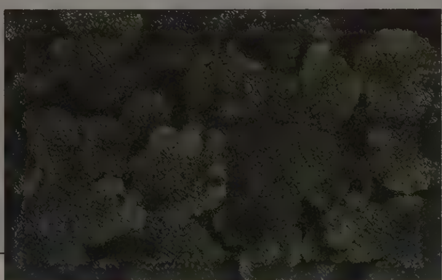
protonema: prot- or proto- (first) + -nema (Gk. NEMA, thread)

The three classes of bryophytes are class Musci (the mosses), class Hepaticae (the liverworts), and class Anthocerotae (the hornworts).

Liverworts

Liverworts are common bryophytes with a life cycle similar to that of mosses. The liverwort gametophyte plant is a narrow, flattened, leathery structure called a *thallus* (pl., *thalli).* The thallus grows along the ground, anchored to the soil by rhizoids growing from the underside.

Marchantia, a common liverwort found near streams and occasionally in greenhouses, has branched, Y-shaped thalli. From the thallus grow short stalks which produce reproductive structures. Antheridia are produced on a flat surface called a *splash platform.* On other stalks archegonia are produced on the undersides of umbrella-shaped structures. Water drops hitting the top of the splash platform splash sperm to the archegonia. The sperm swim to the egg cells in the archegonia. After fertilization of the egg, spore cases develop in sacs under the umbrella-shaped structure.



Economic importance of bryophytes

The only bryophytes regularly used in large quantities are from the genus *Sphagnum.* These peat or bog mosses grow floating on the quiet waters of a pond. As one layer dies and sinks to the bottom, another begins to grow. The mats fill the pond until it becomes a bog. In time other plants begin to grow in the peat moss, and the area shows no evidence of ever having been a pond.

Thick areas of dried peat moss can be cut with saws and burned as a fuel. Gardeners use sphagnum moss to pack plants for shipment. Mixed with heavy soils, shredded peat moss helps the soil to hold more water and is loose enough to permit plant roots to grow easily.

Although man may not use many bryophytes directly, they are important in the ecology of many areas. In tundras, high mountains, rocky areas, or very shaded spots, where most plants cannot grow, mosses prevent soil erosion and even build soil where none had previously been.

The name *liverwort* dates from the ninth century (see p. 6). This box is supplemental and can be omitted.

Dried peat is used as fuel in Iceland and other northern regions.

Because of its superior absorptive quality, peat moss has been used for surgical dressing.

Review Questions 12A-1

1. In what ways are plants valuable to man?
2. List the characteristics of the plant kingdom.
3. What are the three general groupings of plant phyla? What two characteristics are used to put plants into these groups?
4. Describe at least two bryophyte characteristics that limit their size.

Answers–Review Questions 12A-1

1. (1) Plants provide most of man's food. (2) Plants release oxygen needed by man and animals. (3) Plants are raw materials for many manufactured goods (e.g., paper, gum, wax, alcohol, cloth). (4) Plants are a source of beauty.
2. See Appendix B on p. 655.

*3. Plants that lack vascular tissue, plants with vascular tissue that lack seeds, and plants with vascular tissues that produce seeds are the three general groups of plant phyla. The presence or absence of vascular tissues and the production of seeds are the two characteristics that put plants into these groups.

4. (1) Bryophytes have no vascular tissues; therefore, conduction of nutrients through these plants is slower than in vascular plants. (2) They have little support (no woody tissues) and thus cannot grow to great heights.

*From a box.

epiphyte: epi- (Gk. EPI, upon or over) + -phyte (plant)

Vascular Plants Without Seeds

All plants other than bryophytes have vascular tissues which conduct water and dissolved minerals through the plant. Thus the vascular plants are not limited to the small size range of mosses. This group of four phyla, however, are unusual in that they do not produce seeds. In their life cycle they produce *spores,* a single cell with a protective coat, which are used to spread the species. The best known representatives of this group are the ferns.

Phylum Pterophyta: the ferns

The **phylum Pterophyta** (tehr AH fih tuh) contains an interesting and diverse group of plants. Most **ferns** are like the typical forest floor fern or the Boston fern, a favorite potted plant. Some, however, are *epiphytes,** plants that grow on other plants but are not parasitic. In the tropics a few remaining *tree fern* species can be found. Their slender trunks, which may reach over 18 m (60 ft.) high, are really an open network of hard stems, not the solid, woody mass normally associated with such tall trees.

The tree ferns bear huge leaves, often 2-4 m (6-12 ft.) long. Their trunks have been used for construction in the tropics.

Fronds are typically pinnately or bipinnately compound (see pp. 301-3).

Some ferns grow as vines; others grow floating on water. Although they are most prominent in shaded, cooler areas of the tropics, some species grow in almost desert conditions, and others grow next to glaciers. Some ferns are very delicate, among the rarest plants on earth, and quickly perish with the slightest environmental change.

The ferns common to most of North America are typical of the phylum Pterophyta. Each fern leaf, commonly called a **frond,** grows from either a creeping or an underground stem called a *rhizome,* which produces roots. Most fern fronds are long and delicate-looking. Ferns usually grow in clumps, produced by a single rhizome. The rhizome can produce new clumps asexually.

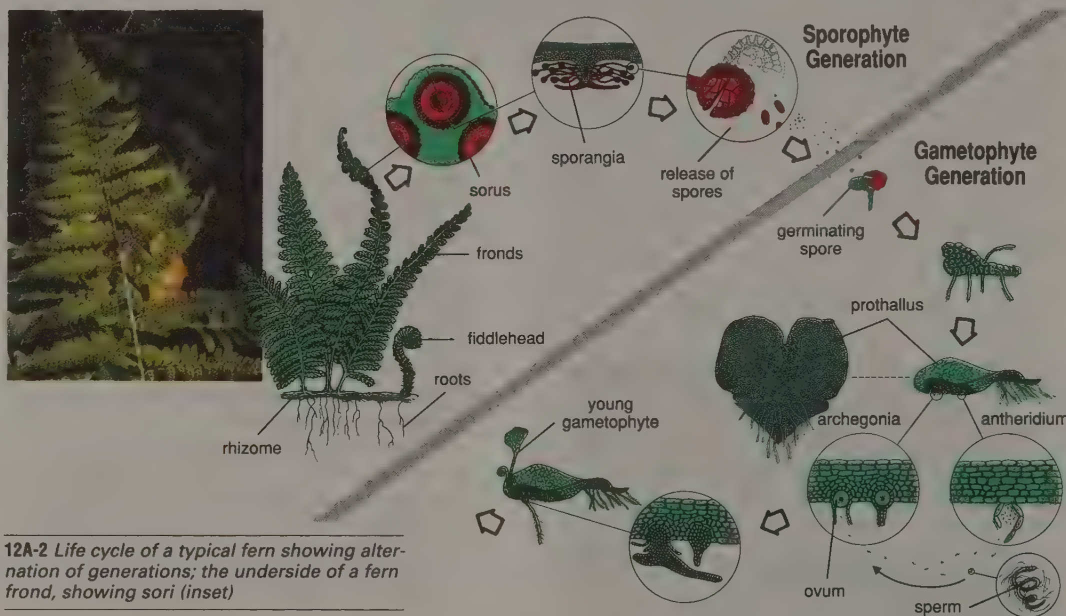
The fern life cycle

Occasionally a person will notice what he thinks are insect eggs or some fungus on the underside of fern fronds. Actually, these are **sori** (SOR EYE) (sing., *sorus*), collections of spore-producing **sporangia.** The sori of various ferns appear different. One characteristic used to name and classify ferns is the location and type of sori. Some ferns have

Microscope slides of the various smaller structures of the fern life cycle are available and can add interest as well as appreciation for relative sizes. If the moss life cycle was omitted, consider omitting this as well.

Potted ferns growing in the classroom are useful for pointing out fern characteristics.

Visual 12A-3 can be used to help teach the life cycle of a typical fern. It points out alternation of generations and the various structures presented in the text. Consider using colored transparencies and pens to enhance the visual.

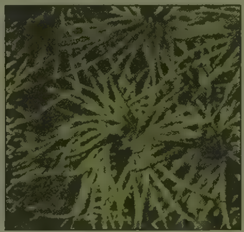


12A-2 *Life cycle of a typical fern showing alternation of generations; the underside of a fern frond, showing sori (inset)*

Minor Seedless Plant Phyla

Sphenophyta: *(horsetails)* Most horsetails grow in wet environments. They have a thick underground stem which continues to grow year after year. From this main stem grow roots and green, erect, annual stems. These stems are ridged, hollow, and segmented by *nodes,* which may produce whorls of branches or of thin, needlelike leaves. Spores form in small, conelike structures at the tops of stems. The stems contain silica deposits. American colonists used the tough, hard nodes to clean pans; hence, the common name, "scouring rushes." Only the genus *Equisetum,* with representatives which grow only about 1 m (3 ft.) high, remains today.

horsetails



ground pine

Lycophyta: *(club mosses)* Club mosses or ground pines look like large moss plants. They usually have a creeping stem which may be under the surface of the soil and occasionally sends up erect stems. These erect stems have spore cases collected into conelike structures either at the tip or at the base of each leaf. Most species are evergreens and are less than 30 cm (1 ft.) high, but one tropical species may reach about 60 cm (2 ft.). Fossil club moss trees have been uncovered that measure over 30 m (100 ft.) high and over 1 m (3 ft.) in diameter.

Psilophyta *(whiskferns)* Whiskferns are rare and unusual plants which lack true roots and leaves. A thick stem covered with rhizoids may creep underground or in horizontal cracks in the bark of tropical trees. From this stem may grow smaller green stems which produce small scales instead of leaves.

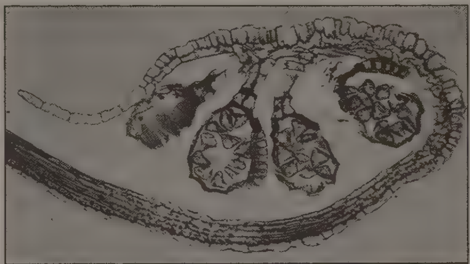
Together these three phyla contain approximately 1,750 living species, all relatively small plants. The fossil record, however, reveals that before the deluge large members of some of these phyla were widespread, possibly as dominant foliage. Fossil Sphenophyta specimens, for example, were large, unusually shaped trees. Most of our coal and oil deposits are thought to be remains of these and similar plants. To have these large plants in abundance would require extensive areas of special environments that we find only in small, isolated areas today. This fact provides further support for the canopy theory.

prothallus: pro- (Gk. PRO, before) + -thallus (to sprout)

The material in this box is supplemental. Consider having students read it; then cover it briefly in lecture. If students are to be responsible for one of these, choose Lycophyta–it is more significant and more common. Specimens of club mosses may be collected and dried for use in the classroom.

fertile fronds, which have spores, and *sterile fronds,* which lack spores. In some ferns the fertile fronds are identical to the sterile fronds except for the presence of the sori. In other ferns the fertile fronds appear different and may not even contain chlorophyll.

When released, the powdery fern spores can be carried by the wind. Under proper conditions fern spores germinate and form a heart-shaped **prothallus*** (proh THAL us) which is one cell layer thick. The underside of the prothallus develops rhizoids (which absorb water and minerals), several *archegonia* (at the notched end of the prothallus), and *antheridia* (near the point of the "heart"). Flagellated sperm are released from the antheridium and swim to the ovum at the bottom of the archegonium. Thus, the prothallus is the gametophyte generation of the fern.



12A-3 *Cross section of a fern frond through a sorus, showing sporangia*

The zygote in the bottom of the archegonium matures and sends the first leaf up and the first root down, beginning the sporophyte generation. The young sporophyte is a parasite on the gametophyte until it is large enough to manufacture

gymnosperm: gymno- (Gk. GUMNOS, naked) + -sperm (seed)

angiosperm: angio- (Gk. ANGEION, vessel) + -sperm (seed)

its own chlorophyll and begin carrying on photosynthesis. Soon after this, the prothallus dies. In ferns the more prominent generation is the sporophyte.

The first leaf of a fern is often a fan-shaped blade. The second is usually a **fiddlehead,** a coiled young leaf. The fiddlehead has tissue in its coiled end which is able to produce new cells even after the base of the leaf has reached its full size. This permits some ferns to have unusually large leaves. Young fiddleheads of some ferns are edible and can be purchased for use in salads.

Review Questions 12A-2

1. Describe the gametophyte and sporophyte of a typical fern. Is their relationship to each other the same as in the mosses?
2. Where are the sporangia of a fern located?
3. How is the life cycle of a fern similar to the life cycle of a moss? In what ways are they different?
4. In what ways are club mosses, horsetails, and ferns similar in their reproductive processes?
5. Describe the gametophyte and the sporophyte of a typical moss. Explain their relationship to each other.
6. Why is water necessary for the sexual reproduction of bryophytes and ferns?

Vascular Plants With Seeds

The vascular plants that produce seeds are divided into two groups: the **gymnosperms*** (JIM nuh SPURMZ) with three phyla and the **angiosperms*** (AN jee uh SPURMZ) with one phylum. The gymnosperms are non-flowering plants that produce seeds which are not enclosed in an ovary when mature. The pine cone, for example, has seeds that lie on tiny shelves when they are ripe. Angiosperms, which are discussed later, produce flowers and have enclosed seeds like the seeds of an apple or an orange.

This box should be read by students, but it is not necessary to spend a lot of time on it in class.

There are no terms in the box which are listed in the Biological Terms section at the end of the chapter. The box presents information regarding the cedars of Lebanon. Teachers may wish to prepare a devotional regarding the cedars of Lebanon (see Ps. 92:12).

Cedrus lebanonae can be found growing in front of many older churches and in some cemeteries. Cedars of Lebanon, although large trees, are small compared to the giant sequoia redwoods. They are also slow growing compared to many of the gymnosperms grown for lumber.

The Cedar of Lebanon and Solomon's Temple

One of the best-known plants in the Bible is the cedar of Lebanon, a gymnosperm of the pine family. These trees reach a height of 30 m (120 ft.) and a circumference of 8 m (25 ft.). After the Flood they were the tallest, most massive trees known in the Middle East. As with most cedars, the wood of these trees is durable since it resists rotting and insect infestation. This wood is also delightfully fragrant and exceptionally beautiful.

Solomon built the temple and his own palace of this wood; his palace is sometimes called "the house of the forest of Lebanon" (I Kings 7:2). Scripture states that Solomon made a pact with King Hiram, the ruler of the Lebanon area, to supply the lumber for this project. Solomon was to send 3 shifts of 10,000 men to help Hiram's slaves and lumbermen cut the trees.

Other rulers, as well as Israelite kings, used this lumber for everything from chariots to ships. No reforestation program was practiced, and today the once extensive forests of Lebanon are mere patches of 30-150 trees each. The cedar of Lebanon, however, is not becoming extinct. It is now protected by the government and is easily cultivated wherever proper soil and climatic conditions exist.

Answers–Review Questions 12A-2

1. In the gametophyte stage, the heart-shaped prothallus produces several archegonia and antheridia. The sporophyte generation begins when the zygote sprouts; it depends upon the gametophyte for nourishment until it is large enough to produce its own food. This stage produces spores (sori). In mosses the gametophyte is the dominant (largest) stage; in ferns the sporophyte is dominant. The stages serve similar functions in both ferns and mosses.
2. In sori on the underside of the frond
3. They both involve alternation of sporophyte and gametophyte generations. In mosses the sporophyte generation appears as a stalk with a capsule containing spores. The fern fronds, on the other hand, serve as the sporophyte generation (dominant stage) and have spores in sporangia on the underside of the frond. In mosses fertilization generally occurs between two separate gametophytes, while ferns are fertilized by sperm and eggs contained in the same gametophyte prothallus.

*4. Spores are produced on leaves or stem tips. The large plant that produces the spores is the sporophyte generation.

5. The leafy shoot, which produces the gametes, is the gametophyte. The sperm fertilize the eggs and thus form the sporophyte generation. Each fertilized egg cell grows into a stalk with a capsule. This is the sporophyte stage: it is diploid and depends upon the gametophyte. Spores are produced, released, and eventually develop into the gametophyte stage.
6. Water is necessary to transport the sperm to the egg cell of the archegonium for fertilization.

*From a box.

Useful Gymnosperms

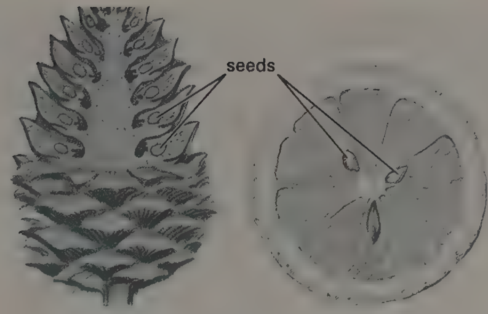
When we think of useful plants we usually think of those we eat. Except for pine-needle tea (a bitter brew, sometimes causing minor undesirable side-effects), gymnosperms are rarely consumed by humans. Since gymnosperms are all woody trees or shrubs, there are few parts that humans find appetizing.

When many of us think of gymnosperms we think of the over 20 million that are cut each year to supply American homes with Christmas trees. Sometimes the gymnosperms are called evergreens. Although many of them are green throughout the year, many gymnosperms lose their foliage in the fall. And some plants, such as holly, are not gymnosperms but keep their green leaves all year.

The primary economic importance of gymnosperms is in lumber and pulp. America was literally built from the gymnosperm forests that covered extensive areas of the continent. But Americans rashly used almost all the available virgin timber. Over 100 yr. ago nearly every accessible stand of the eastern white pine, a highly prized lumber tree, had been cut. Today most of the lumber and pulp used in America comes from cultivated gymnosperms, specially selected for rapid growth and quality lumber. These trees can be harvested every 20-30 yr.

Gymnosperms range from ornamental varieties which creep along the ground to the giant Founder's Tree, a coastal redwood over 110 m (365 ft.) tall. The bristlecone pine is a species of gymnosperm growing in a dry mountain region of California. By making special drillings, scientists found that one of the bristlecone pines is the oldest living thing. According to the number of its growth rings, it is more than 4,000 yr. old.

bristlecone pine



12A-4 *A pine cone has seeds on scales; an orange has seeds enclosed in an ovary.*

Phylum Coniferophyta: conebearing plants

Among the gymnosperms the **phylum Coniferophyta** (KAH nih fur AH fih tuh) is the largest. All **conifers** produce seeds in cones. Although not all cones are like the familiar pine cone and not all conifers look like pine trees, the life cycle of a pine tree is typical.

In the spring, pine trees produce two types of cones: *pollen cones* and *seed cones*. **Pollen cones,** usually numerous, small, and short-lived, are found near the tips of the branches. The abundant **pollen** produced by these cones contains the male reproductive gametes. The chance of fertilization would be very small if only a few grains were produced since pine pollen is carried to the seed cones by the wind.

Pollen lands on the open scales of the small, green, upright **seed cone,** usually found on other branches of the same tree. The scales then close tightly, and in many pines the cone begins to point downward. The ova on the scales of the seed cone may not be fertilized until months later, and in some species they may not develop into seeds for several years. When the seeds are mature and environmental conditions are right, the scales of the woody seed cone open and release the seeds.

In the phylum Coniferales are several distinct families. Although most of the families in this order have cones like the pine tree, some of the cones are very different.

❑ *The pine family* is the largest and most economically important conifer family. The pines have the needles and cones normally associated with

This box should be read by students, but it is not necessary to spend much time on it in class.

There are no terms in the box which are listed in the Biological Terms section at the end of the chapter. The box presents interesting material about diverse gymnosperms.

Pine-needle tea can cause bowel movement problems. Pine cones are eaten by many animals, including squirrels and birds.

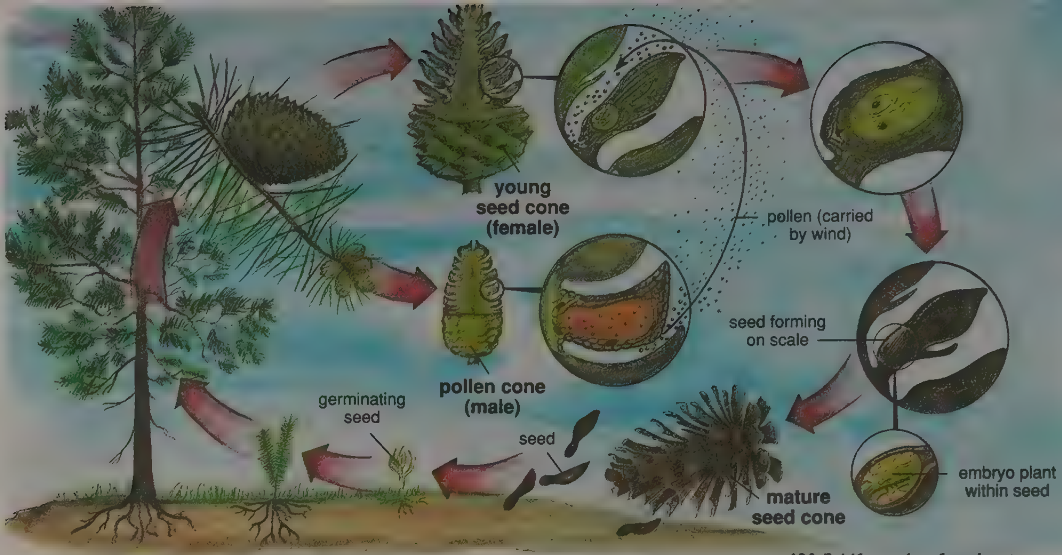
Gymnosperm pollen often forms conspicuous yellowish drifts on the surface of lakes and ponds.

The seeds of pines are a source of food for many birds, rodents, and other animals, which reduces the reproduction rate of the trees.

Visual 12A-4 can be used to teach about the life cycle of a typical pine. It points out the various structures presented in the text. Consider using colored transparencies and pens to enhance the visual.

The Douglas firs of the pine family provide more than $\frac{1}{4}$ of the timber cut in the United States for construction.

It is suggested that students learn the four Coniferophyta families presented in the text. (Omit the yew family if desired.)



12A-5 *Life cycle of a pine tree*

Thoroughly cover the pine life cycle. Slides are useful in teaching the processes.

gymnosperms. Pine needles vary in length, roundness, the number in a cluster, and the presence or absence of stripes. These characteristics, along with the type of cone produced, are used to classify the pines, firs, hemlocks, and the other members of this group.

❑ *The yew family,* prized in gardens for its slow growth and waxy green needles, produces fruit that looks like red, open-ended berries.

❑ *The cypress family* includes the *junipers* and the *arborvitae,* both widely cultivated shrubs. Some members of this family bear small, dry

This box is supplemental. Consider having students read the box; then cover it briefly in class.

There are no terms in the Biological Terms section from this box. The box presents that there are other gymnosperms than the familiar ones.

Point out that of the three phyla of gymnosperms, most living species are in only one phylum. It is suggested that students learn the common names of cycads and ginkgos.

Minor Gymnosperm Phyla

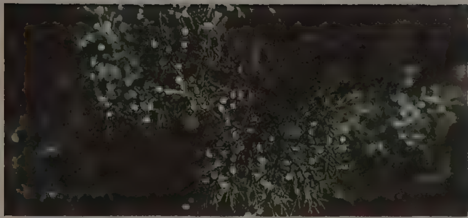
Many of the extinct gymnosperm species were very unlike those alive today. For many years scientists classified with the ferns certain fossil trees with fernlike fiddlehead leaves. When they found seeds attached to the leaves, however, these trees were named *seed ferns* and reclassified as extinct gymnosperms.

The *cycads* comprised a large gymnosperm phylum before the deluge. Only about a hundred species remain in phylum *Cycadophyta.* The cycads look like palm trees, and some of them have fiddleheads. Sometimes called the *sago palms,* these plants bear seeds in conelike structures.

Botanists once thought that all members of the phylum *Ginkophyta* were extinct. In the last century, however, they discovered several large specimens being cultivated in monasteries in China. Today *ginkgo* trees (also called maidenhair trees) can be found in parks all over the world. The ginkgo sheds its broad, leathery, fan-shaped leaves during late autumn. Ginkgo trees are either male, producing pollen, or female, producing yellowish, cherry-sized, foul-odored fruit.

cycad

ginkgo leaves



12A-6 *A juniper showing scales and cones*

cones, but others have cones that remain fleshy and look like blue-green peas. Most junipers and arborvitae have overlapping evergreen *scales* instead of needles.

❑ *The redwood family* contains some of the largest living things in the world: the giant sequoias. The living organism with the greatest mass is the General Sherman giant sequoia (sih KWOI uh) tree in California. It is 25 m (84 ft.) in circumference and 83 m (273 ft.) tall and has bark about 30 cm (1 ft.) thick. It has been estimated to be about 3,500 yr. old.

Phylum Anthophyta: the flowering plants

Phylum Anthophyta, (an THAH fih tuh) often called angiosperms are the dominant vegetation on the earth today. There is so much diversity among the 250,000 species that they are grouped into nearly 400 different families, based primarily on floral parts. All angiosperms have seeds enclosed in an ovary and flowers. Many angiosperms (or **flowering plants**), however, do not produce colorful blossoms. Corn tassels and the catkins of oak trees are flowers.

An *ovary* of a plant is the structure which encloses the seeds; a mature ovary is a **fruit.** You can easily identify apples, cherries, and tomatoes as fruits. But pods of peas and kernels of corn and wheat are also fruits (see page 335).

Monocots and dicots

Angiosperms are divided into two classes, *Monocotyledoneae** (MAHN uh KAHT uh LEE duh nee) and *Dicotyledoneae** (dye KAHT uh LEE duh nee), commonly called **monocots** and **dicots.** The basic distinction between these two is the number of cotyledons in the seed. A **cotyledon** (KAHT uh LEE dun) has stored food to keep the embryonic plant alive while it is in the seed and to supply the sprout with energy until it can carry on photosynthesis. The peanut, a dicot, easily splits in

Monocotyledoneae: Mono- (single) + -cotyledon (Gk. KUTOLEDON, hollow-shaped cup)

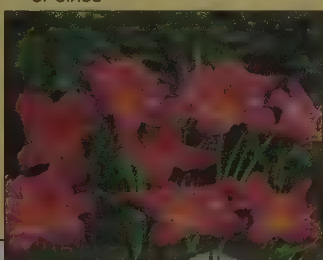
Dicotyledoneae: Di- (two) + -cotyledon (hollow-shaped cup)

Have students turn to pages 656-57 and look over the list of monocot and dicot families and examples to get an idea of what these two classes are like. Do not have students memorize the families, but explain that having a knowledge of what kinds of plants are in each group is helpful.

Stress to the students that they should know this table. Classifying some classroom examples based on the information in this chart can be profitable.

12A-7 **Comparison of Monocot and Dicot Characteristics**

	Monocot	Dicot
Seeds:	One cotyledon One seed leaf	Two cotyledons Two seed leaves
Leaves:	Parallel venation	Netted venation
Roots:	Usually fibrous	Usually a tap root
Stems:	Young stems have scattered vascular bundles and usually become hollow as they mature	Young stems have vascular bundles in a ring and are usually solid
Flowers:	Flower parts usually in threes or sixes	Flower parts usually in fours, fives, or in multiples of these numbers



daylilies

columbines

Answers–Review Questions 12A-3 *(p. 298)*

1. Pollen cones contain male gametes and appear near tips of branches in spring; they are usually numerous, small, and short lived. Seed cones are small, green, upright cones containing eggs that are fertilized by pollen; they then produce seeds.

2. Pines produce seeds rather than spores. Pollen grains are also carried by wind rather than being transported only by water in the process of fertilization. There is alternation of generations, but it is not as easily observed as in ferns and mosses.

The angiosperms range from the eucalyptus tree, which may be 92 m (300 ft.) tall, to the duckweeds, which are floating plants only 1 mm long. Specimens of both can be easily obtained.

half to reveal its two cotyledons. Corn, on the other hand, is a monocot. A corn seed has only one cotyledon and does not split apart. A characteristic that distinguishes between monocots and dicots is the number of leaves the embryonic plant has. Monocots have one; dicots have two.

Leaf venation can often be used for classification of monocots and dicots. Monocots generally have *parallel leaf venation.* The veins in their leaves start at the stem, which may be underground and go to the top of the leaf. The veins are roughly parallel. Dicots generally have *netted leaf venation.* Netted veins continually branch within the leaf blade. Problems may arise in classifying plants by leaves if one is considering a modified leaf, like a cactus needle, or a leaf that is too thick to have visible venation. Of course, some plants that have leaves are not even angiosperms.

Monocots usually have floral parts in threes or sixes. Dicots, like the rose or carnation, usually have floral parts in fours, fives, or multiples of four or five. Classification by floral parts can be misleading, and there are exceptions. Other characteristics used to determine whether a plant is a monocot or a dicot are even less reliable.

Angiosperms are classified into families based upon their reproductive structures. A few of the more important plant families and some common examples of each are listed in Appendix B.

Biological Terms

botany
kingdom Plantae
vascular tissue
seeds

Non-Vascular Plants
phylum Bryophyta
leafy shoot
rhizoid
gametophyte
archegonium (pl., archegonia)
sporophyte
protonema

alternation of generations
dominant generation

Vascular Plants without Seeds
phylum Pterophyta
fern
frond
sori
sporangium (pl., sporangia)
prothallus
fiddlehead

Vascular Plants with Seeds
gymnosperm
angiosperm
phylum Coniferophyta
pollen cone
seed cone
pollen
phylum Anthophyta
flowering plant
fruit
monocot
dicot
cotyledon

Answers begin on page 297.

Review Questions 12A-3

1. Name and describe the two types of cones produced by conifers. Tell their relationship to each other.
2. How is the life cycle of a pine different from the life cycle of a fern or moss?
3. List several well-known groups of conifers, and describe each.
4. What characteristics do gymnosperms and angiosperms have in common? In what ways are they different?
5. What are the primary characteristics that separate the two classes of the phylum Anthophyta?

Thought Questions

1. If you examine a clump of moss, you will find that only some of the moss has sporophyte stalks and capsules. Why?
2. What is meant by alternation of generations in the plant kingdom, and how do the moss and fern life cycles illustrate alternation of generations?
3. Why would mosses be most abundant in areas such as the tundra and tropical rain forests, where extreme environmental conditions exist?
4. What evidence does the plant kingdom give to support the canopy theory?
5. Seed plants are called the dominant vegetation of the earth today. In what ways are seed plants dominant over other types of plants?

3. **(1)** Yews are slow growing, have waxy green needles, and produce red, open-ended berries. **(2)** Cypresses (junipers and arborvitae) are generally shrubs that produce either small, dry cones or fleshy cones (like blue green peas); they have scales instead of needles. **(3)** Pines are the largest family; they produce various sizes of needles and typical cones.
4. Both produce seeds (ova fertilized by pollen). Gymnosperms lack flowers but possess cones; angiosperms lack cones but possess flowers.
5. See 12A-7 on p. 297.

Answers–Thought Questions

1. About half of the gametophytes are male.
2. The term *alternation of generations* refers to the two generations (physical forms) that develop in the life cycle of the plant. The sporophyte produces the gametophyte, and the gametophyte produces the sporophyte; thus, they alternate.
3. Mosses tolerate a wide variety of environments. Some thrive only in colder, moist regions, while others grow only in warmer, wet areas. However, all mosses require moisture for fertilization.
4. There is fossil evidence to indicate that most plants were larger, more abundant, and more widely distributed sometime in the past. For example, there are fossils of palm leaves in Antarctica and vast deposits of peat bogs, which indicate a more favorable environment for rapid growth of most plants. Such a favorable environment can be explained by the canopy theory.
5. They are larger and cover more land area per plant; they are more conspicuous; they are more important for our survival.

12B-Plant Anatomy

Plant parts can be classified as woody or herbaceous. The trunk and branches of a tree are *woody*. Woody parts generally are strong because their cells have thick walls. In most woody plant parts some tissues remain *undifferentiated* (do not become specialized). Additional plant tissues can form from this undifferentiated tissue in future years. This growth may continue for centuries and produce tall trees with thick trunks.

Herbaceous (hur BAY shus) plant parts, on the other hand, usually live for only one year. Because leaves, flowers, and nonwoody roots and stems lack the thick cell walls of woody structures, they sometimes rely on turgor pressure for support. The herbaceous parts of a plant usually remain green until they die. When dead, many herbaceous plant parts, such as corn stalks, are strong and leave stems which appear woody.

Herbaceous plants lack woody structures; those that have both woody and herbaceous structures are called *woody plants.*

Plant organs and tissues

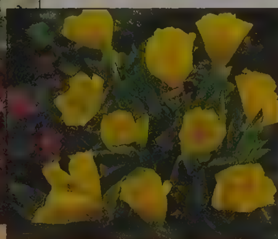
Plant organs can be divided into two groups: the **vegetative organs** (leaves, roots, and stems) and the sexual **reproductive organs** (flowers, fruits, and seeds). Technically, leaves, roots, and stems are vegetables. Examples include spinach, carrots, and asparagus. The other parts of a plant are either fruits or seeds. Peas and corn are really seeds; eggplants and tomatoes are really fruits.

Although of great diversity, plant organs are made of the same basic kinds of tissues which can be grouped into three categories.

❑ **Meristematic** (MEHR ih stuh MAT ik) **tissues** Plant cells capable of mitosis are usually found only in meristematic tissues. Meristematic cells are small, thin-walled, and undifferentiated, but can develop into any tissue found in that particular plant. Meristematic tissues are found in the growing areas of plants, such as buds, tips of roots and stems, vascular bundles of some herbaceous plants, and roots and stems of woody plants.

❑ **Vascular tissues** Vascular tissues are *complex tissues;* that is, they are composed of different types of cells. The **xylem*** (ZYE lum), for example, is made of long, thick-walled cells and

◀ sweet Williams



▼ evening primroses

Annuals, Biennials, and Perennials

Based on the length of time that they grow, plants can be placed into three groups.

❑ **Annual plants** Most herbaceous plants are annual plants. Annuals sprout, grow, flower, and produce seeds in one growing season. Many showy flower beds contain herbaceous annuals like zinnias, pansies, and marigolds.

marigolds

❑ **Biennial* plants** Biennials like the foxglove and the sweet William sprout and develop in one growing season but do not flower and produce seeds until the following growing season. After the second year most biennials die.

❑ **Perennial plants** Perennials grow year after year. Woody plants are usually perennials, but some herbaceous plants have thick, underground stems which live many years, even though the above-ground leaves and stems die each year. Tulips, irises, peonies, and gladioli are common examples of *herbaceous perennials.*

biennial: bi- (two) + -enni-al (L. ANNUS, year)

xylem: (Gk. XYLON, wood)

Tomatoes may be classified by home economists as vegetables because of the way they are served. Technically, they are fruits. Peas are not vegetables but seeds. Green beans are fruits and seeds.

Consider reviewing the structures and life processes of a typical plant cell (Ch. 3A, especially p. 78).

This water-conducting system is highly efficient; a large plant may lose 400 L (100 gal.) of water from its leaves in one day, which is much more than the amount present in its stems at any one time. The vascular system also supports the plant body. Conducting tissues are present in roots, stems, and leaves and literally bind the plant together.

The *Annuals, Biennials, and Perennials* box is supplemental material that should be covered by all students. The concept is easy, and it is a common method of grouping plants, especially in the gardening trade. The three kinds of plants are found in the Biological Terms section at the end of the chapter.

12B–Plant Anatomy

Notes–Chapter 12B

Plant anatomy can be a boring subject if it is taught for total mastery. It can also be frustrating if the teacher omits a large amount of material and then expects detailed mastery of certain points. One general tendency is to skim over plant anatomy and then push hard on plant physiology found in the next chapter. But without adequate knowledge of plant anatomy, plant physiology does not make sense.

It is suggested this chapter be taught rapidly, surveying all material and stressing the highlights. Be careful not to stress insignificant material.

Teach this chapter using many specimens. When leaves are discussed, ask students to bring in leaves to examine. Look for leaves in grocery stores, florist shops, nurseries, garden centers, and on potted plants if this unit is being taught in midwinter. Slides of leaf cross sections can be compared to see their different characteristics; a microprojector is useful here. Sprouting bean seeds add to the discussion of roots. Radishes, carrots, and beets from the grocery and one or two uprooted potted plants can also add to the root illustrations. A collection of dormant twigs (one for each student) and several slices of tree trunks (hopefully of different trees from your area) can create interest and aid the students' understanding.

phloem: (Gk. PHLOOS, bark)

All but *collenchyma* and *sclerenchyma* are boldface terms in other parts of this chapter. Learning the chart, however, would seem like meaningless detail to the students. It is recommended that only the vascular tissues, the xylem and phloem, be presented from the chart at this time. After covering the chapter, point out that this chart is a good place to review these structures. Using a paper to cover the names, students should be able to come up with the names from the function, structures, and location. From the uncovered names, students should be able to give *some* of the functions and locations for each tissue and a few of the structure notes as well.

It is recommended that advanced classes concentrate on the four types of cells found in xylem and the three types found in phloem.

Visual 12B-1 can be used as an overview or a review of plant tissues. It is wise to point out to students which of the tissues they should know and to add any points to the visual that are important for them to know. Point out that the chart on this page contains all of the information presented on the visual, so students will not need to copy the visual.

Use potted plants to demonstrate this material.

Plant Tissues

	Names	Function	Structure	Location
Meristematic	Apical meristem	produces new cells for growth in length and formation of leaves and flowers	cone-shaped mass of small, thin-walled cells	at the ends of stems and roots and in buds
	Vascular cambium Lateral meristem	produces new xylem and phloem for growth in diameter	layer of small, thin-walled cells	between the xylem and phloem in woody and some herbaceous stems and roots
	Cork cambium	produces cork cells	layer of small, thin-walled cells	inside cork cells of bark
	Pericycle	produces secondary roots	layer of small, thin-walled cells	inside the vascular cylinder of young roots and stems and inside the cortex layer of the bark and roots
Vascular	Xylem	conducts water and dissolved minerals upward	complex tissues made of • *tracheids:* long cells; dead at maturity; strengthening • *vessels:* long tubes formed by many dead cells lined end to end; conduction • *fibers:* long cells with thick walls; strength • *parenchyma:* shorter cells used for storage	in all vascular bundles of young or herbaceous plants; comprises all woody parts of plants
	Phloem	conducts water and foods downward	complex tissues made of • *sieve tubes:* rows of long, living cells with perforated ends; conduction • *companion cells:* found near sieve tubes; appear to aid them in conduction • *fibers and parenchyma:* same as in xylem	in young or herbaceous parts of plants along with the xylem; comprises part of the bark of woody plants
Structural	Epidermis	protects; covers	one cell layer thick, often with a secreted waxy cuticle; forms guard cells for the stoma which permit exchange of gases; usually lacks chlorophyll and other pigments	on leaves, young roots and stems, and other exposed areas of the plant; comprises the top layer of cells
	Parenchyma	stores food; manufactures food	large cells with thin walls; usually contains plastids; cells of various shapes	in cortex of roots and stems and in fruits
	Palisade mesophyll	manufactures food	cells arranged in neat rows, closely packed; contains many chloroplasts	upper layer of mesophyll of leaf
	Spongy mesophyll	manufactures food	cells loosely arranged with many air spaces; also contains chloroplasts	lower layer of mesophyll of leaf
	Collenchyma	strengthens	thick-walled, long-lived cells	in stems and leaf veins
	Cork	protects; waterproofs	small cells which die and fill with material soon after they are formed	in tree bark and skins of underground structures
	Sclerenchyma	strengthens	cells with thick walls; called *fiber cells* or *stone cells*; dead at maturity	in vascular tissues; common in various hard parts

carries water and dissolved minerals within a plant. When xylem tissue is mature, the cells die, leaving long conducting tubes. The cell walls of another tissue, the **phloem,*** (FLOH EM) are usually slightly thinner than xylem cell walls. Mature phloem is composed of living cells and carries water and dissolved foods (usually sugars). Generally, materials in xylem tubes move upward, and materials in phloem cells move downward. However, in some parts of the plant and at another time of the year, the opposite can be true. For example, during the summer, sugars produced in the leaves are carried in the phloem to the roots. But in the spring tree, phloem may carry water

Objectives–Chapter 12B

- ❑ List the functions of a plant's vegetative and reproductive organs.
- ❑ List and describe some of the specialized tissues of an angiosperm.
- ❑ Distinguish between woody and herbaceous plants and between woody and herbaceous plant parts.
- ❑ Distinguish among annual, biennial, and perennial plants.
- ❑ Draw and label a cross section of a leaf and give the functions of the structures shown.
- ❑ Recognize external structures of a leaf.
- ❑ Explain the opening and closing of stomata.
- ❑ Explain why leaves change color and drop in autumn.
- *❑ List and describe examples of leaf modification, root modification, and underground stems.
- ❑ Describe the structures and functions of roots.
- ❑ List and distinguish between the primary and secondary tissues of both roots and stems.
- ❑ Distinguish between primary and secondary growth in woody roots and stems.
- ❑ Describe the external anatomy of a dormant woody twig.

*From a Facet.

and food upward. The sap rises to help with the formation of leaves and flowers.

❑ **Structural tissues** The structural tissues include those which produce food, store food, cover, support, and protect the plant. Some of these tissues are thin and delicate while others may remain years after the plant is dead. These tissues will be discussed as the plant organs are covered.

petiole: (L. PETIOLUS, fruit stalk)

Review Questions 12B-1

1. Differentiate between woody and herbaceous plant parts.
2. Describe and give the functions of the three major categories of plant tissues.
3. Compare and contrast xylem and phloem.

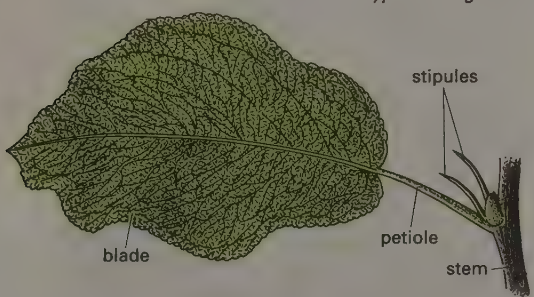
The Leaf

One of the primary functions of a leaf is absorbing energy from the sun. Without this efficient energy-gathering, enough photosynthesis to support the plant would not take place. Ranging in size from a fraction of a centimeter to over 4 m (15 ft.) long, leaves may be thick and heavy or light and delicate. Whereas most leaves are a deep, rich green, some are pale green, yellow, red, pink, or even white. Although modified leaves may help protect the plant, attract and catch insects, store water, or even hold the roots of the plant to a tree trunk, the basic function of typical leaves is photosynthesis.

Structures of a typical leaf

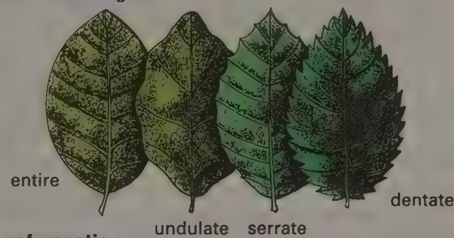
A typical *foliage leaf* has a large, flattened area called the **blade,** which is connected to the stem by a stalk called a **petiole.*** Some leaves, like those of a zinnia, lack a petiole and are called *sessile*. Some leaves have **stipules,** which may be thin tissues that covered the leaf when it was forming, winglike structures attached to the petiole, or leaflike structures at the base of the petiole.

12B-1 *A typical foliage leaf*



Botanists identify plants by studying the basic shapes of the leaves and leaf parts, including the edges of the leaves called *margins*. Identifying plants by their leaves, however, is not always foolproof. One type of oak may have over twenty different leaf shapes on a single tree.

12B-2 *Leaf margins*



Identify several plants whose leaves have these shapes.

Leaf venation

There are two basic patterns of **leaf venation:** parallel and netted. In **parallel venation** a series of veins originates at the stem and proceeds to the top of the leaf in a roughly parallel fashion. This occurs in monocots like corn, grass, irises, and orchids.

In **netted venation** large veins branch to form a network of smaller veins throughout the leaf. There are two types of netted venation. If the veins branch off one large central vein (the *midrib*), the venation is **pinnate.** Oaks, African violets, and apple trees have simple pinnate leaves. If there are two or more main veins coming from a single point, the venation is **palmate.** Maples, ivy, and geraniums have simple palmate leaves.

If there is only one blade on one petiole, the leaf is a *simple leaf*. If a leaf on a single petiole is divided, the leaf is a *compound leaf*. Each of these blade divisions is called a **leaflet.** If the leaf

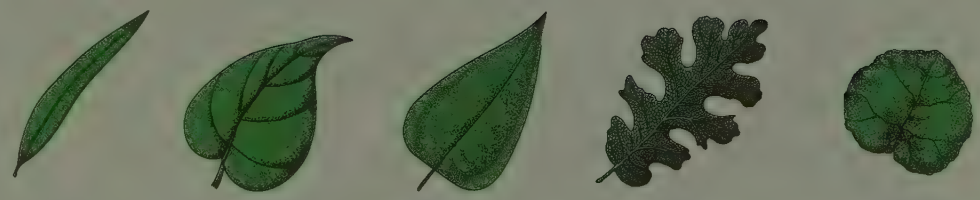
Stipules are usually small, but in some plants, such as the garden pea, they can function as photosynthetic organs. Stipules may also be in the form of thorns.

Visual 12B-2 can be used to present leaf margins, leaf shapes, and leaf mosaics (not covered in the text, but discussed in the laboratory manual) to the class.

Answers–Review Questions 12B-1

1. Woody plants have thick cell walls; in most, some cells remain undifferentiated, permitting a continuing growth in size. Herbaceous plants usually live only one year; they usually lack thick cell walls and rely on turgor pressure for support. They usually appear green until they die.
2. **(1)** Meristematic tissue cells are small, thin-walled, and undifferentiated but can develop into any tissue found in the plant. These tissues contain only cells which are capable of mitosis for growth; they are found in buds, tips of stems, roots, and in the vascular bundles of herbaceous plants. **(2)** Vascular tissues are complex tissues composed of different cell types; xylem has long, thick-walled cells which carry water and dissolved minerals upward; phloem has cell walls slightly thinner than xylem; it carries water and dissolved foods downward. **(3)** Structural tissues carry on photosynthesis; store food; and cover, support, and protect the plant (e.g., the cells in stems and leaves).
3. Xylem has long, thick-walled cells; it carries water and minerals through the plant (usually upward); when xylem tissue matures, its cells die and leave long conducting tubes. Phloem has cell walls usually slightly thinner than those of xylem; mature phloem is composed of living cells which generally conduct water and food (usually sugars) downward (except in spring).

12B-3 *Leaf shapes*



cuticle: (L. CUTIS, skin)

stomata: sing. stoma (Gk. STOMA, mouth)

Potted plants are useful in demonstrating leaf structure.

Epidermal cells are usually transparent, permitting passage of sunlight into the leaf. They vary in thickness, being thicker in the plants found in dry regions.

It is the breaking of epidermal hairs of poison ivy which releases the poison. Researchers have found that the juice of the leaves of several common weeds in the genus *Plantago* (plantain) is effective in relieving the rash and itch of poison ivy. It is an excellent home remedy, which cannot be prescribed or marketed until the "active ingredient" is identified and thoroughly tested, a process that would take more time and money than the discovery may be worth.

Temperatures higher than 30 to 35° C (86 to 95° F) and an increase in carbon dioxide concentration in intercellular spaces can cause stomata to close. Exposing a plant to light after hours in darkness can cause its stomata to open.

The English oak may have 45,000 stomata per square centimeter on its lower epidermis, while some monocots have fewer than 2,500 per square centimeter.

is basically pinnately veined and the leaflets are arranged down the midrib, the leaf is *pinnately compound.* If the leaf is palmately veined and all the leaflets originate from a single point, the leaf is *palmately compound.* Occasionally there is a *bipinnately compound* leaf, in which the venation is pinnate with the leaflets borne on the secondary veins, not just on the midrib. Some plants even have tripinnately compound leaves. Can you figure out how they look?

Some leaflets are larger than many simple leaves, and a petiole may look like a stem rather than like part of the leaf. One of the easiest ways to tell the difference between a leaf and a leaflet is to look for a stipule. Leaflets usually do not have stipules, but most leaves do. Another distinguishing characteristic is the presence of buds. A bud may be found at the base of a petiole, not at the base of a leaflet. Leaves are found in different planes on a stem, but leaflets are always found on the same plane.

The covering of a leaf

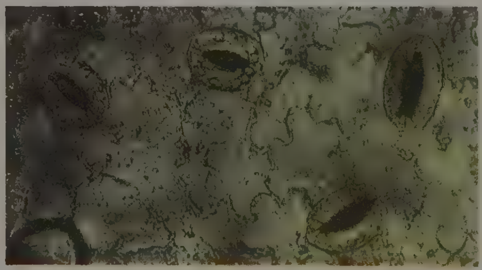
If you were to look at a cross section of a typical leaf under a microscope, you would notice that it appears to have layers of tissue. The top and bottom layers, which are one cell thick, comprise the **epidermis.** The epidermal cells lack chlorophyll and serve as protection.

Often epidermal cells secrete a waxy substance that forms a **cuticle,*** giving the leaf a shiny appearance on one or both surfaces. The epidermal cells of some leaves produce *epidermal hairs.* Epidermal hairs may be extensions of epidermal cells, or they may be composed of several cells. Sometimes these hairs give the leaf a velvety appearance, as in African violets. Some epidermal hairs secrete sticky substances or chemicals with specific odors. If you touch a geranium leaf, you will notice a distinctive scent released by the broken epidermal hairs. Some epidermal hairs are thin and sharp enough to penetrate your skin without your feeling the prick. Stinging nettles, moreover, leave an irritating substance under the skin.

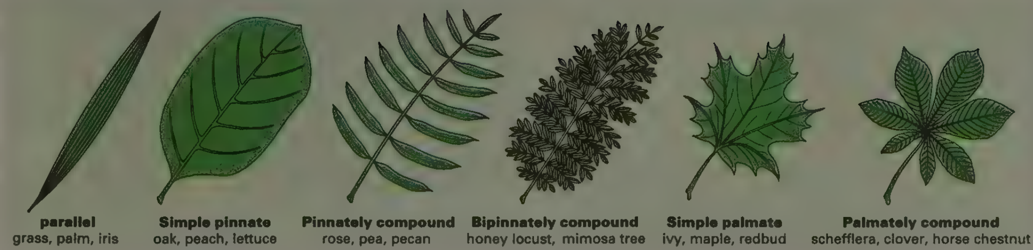
On the underside of most leaves are little openings called **stomata,*** which permit the exchange of gases between the atmosphere and the spaces inside the leaf. Around each stoma are two **guard cells.** These specialized epidermal cells are shaped in opposing crescents. Guard cells contain chlorophyll and manufacture sugars which, in different concentrations, cause the water pressure in the cell to change. When guard cells are turgid, they open the stomata, but when lacking water, they collapse and close the stomata.

Enzymes, temperature, and other factors play important roles in the opening and closing of the stomata. Generally, when water is in abundance and photosynthesis is taking place, the stomata are open. At night, or when the plant lacks water, the stomata are closed to reduce loss of water into the atmosphere.

12B-4 *Stomata surrounded by guard cells; some stomata are open, others are closed.*



12B-5 *Leaf types and venations*



The stomata of different plants vary in size, number, and location. A lily pad has all its stomata on the upper epidermis; in apple leaves all the stomata are on the lower epidermis. Oat leaves have an almost equal number of stomata on both the upper and lower epidermis. The potato is about average, with 5,100 per sq. cm. on the upper epidermis and 16,100 per sq. cm. on the lower epidermis.

The inside of the leaf

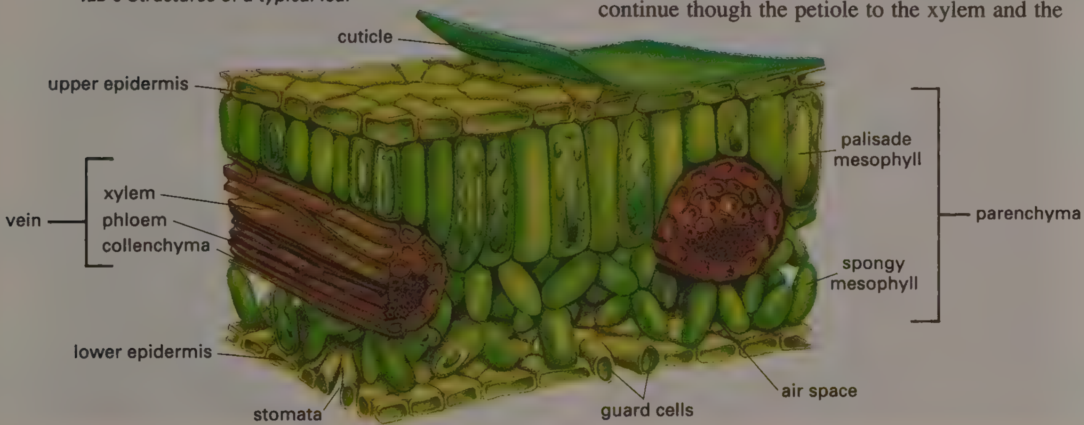
Between the upper and lower epidermis is the mesophyll. These **parenchyma*** (puh RENG kuh muh) tissues are the primary photosynthetic areas of the leaf. The upper layer or layers are called **palisade mesophyll*** (MEZ uh FIL). These mesophyll cells are column-shaped and are lined up side by side. This arrangement permits a large number of cells to be present in a small surface area. These cells have abundant chloroplasts which move in a circle around the central vacuole by cytoplasmic streaming. Each chloroplast gets its turn at the top of the cell where it can absorb the most direct sunlight.

The **spongy mesophyll** is made of irregularly shaped cells with many air spaces between them. These air spaces do not permit this layer to have as many chlorophyll-containing cells as the palisade layer. For this reason the underside of many leaves is not as dark a green as the upper surface. Many vertical leaves, however, have two layers of palisade mesophyll with a layer of spongy mesophyll in the middle.

Plants do not inhale and exhale air as you do, but in a sense plants do breathe. Gas exchange through the stomata and diffusion in the air spaces of the spongy mesophyll supply the carbon dioxide and oxygen exchange necessary for photosynthesis.

The xylem and phloem in the *veins* of the leaf continue though the petiole to the xylem and the

12B-6 *Structures of a typical leaf*



parenchyma: par- (beside) + -en- (in) + -chyma (Gk. KHEIN, to pour)

mesophyll: meso-, or mes- (Gk. MESOS, middle) + -phyll, or -phyllum (leaf)

Visual 12B-3 can be used to teach leaf venation. Place the visual under a clear visual or the acetate roll found on some overhead projectors. Use a green pen to draw the leaf blade around the venation while describing simple leaf venation; then discuss variation and show examples. When it is time to present pinnately compound, put a new, clear visual over the transparency or advance the acetate roll and draw a different leaf blade on the pinnate venation. Discuss variations and show examples. Then present palmately compound; discuss variations and show examples. Repeat the procedure for bipinnately compound.

In some plants (corn, grasses, many aquatics, and conifers) the mesophyll is only slightly differentiated into palisade and spongy tissue. Parenchyma cells containing chloroplasts (called chlorenchyma cells) can be found also in stems, twigs, and unripe fruits.

Visual 12B-4 can be used to teach the structures of a typical leaf. Use a green marker to color the chloroplasts. Other markers can be used to highlight other structures.

abscission: ab- (away from) + -scission (to cut)

anthocyanin: antho- (Gk. ANTHOS, flower) + -cyanin (greenish blue)

This box is supplemental but contains material with which students should be familiar. Consider having students read the box, and then skim it in class.

The terms **deciduous, abscission layer, persistent foliage, carotenoid,** and **anthocyanin** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes. It is suggested that students know *carotene, xanthophylls, anthocyanins,* and *tannic acid* for testing purposes.

The impact of rain upon the leaf, the formation of ice crystals in the abscission layer, and the shrinkage of the petiole on sunny days hasten the fall of the leaf.

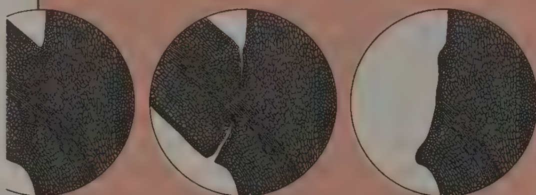
Leaf abscission is economically important in cotton; it is essential for machine picking and greatly aids hand-picking of the bolls. To hasten leaf fall, farmers use chemicals which artificially induce abscission.

Good sources for vitamin A are carrots, winter squash, pumpkin, sweet potatoes, and spinach.

Falling Leaves

In the tropics and subtropics where the growing season lasts almost all year, most plants lose their leaves a few at a time and are never completely bare. Most house plants are tropical plants and therefore have leaves all year.

In more temperate regions many woody plants are **deciduous;** they lose their leaves before winter in order to conserve water. A deciduous leaf has a narrow, light green layer at the base of the petiole. This **abscission* layer** is formed even before the leaf is completely developed. Part of this layer is made of cells which begin to die as the days shorten, regardless of the temperature. For this reason deciduous plants that are kept indoors still lose their leaves in the fall. The abscission layer also forms a layer of cork cells that seals the vascular tissues and leaves a *leaf scar* on the stem. Approximately 2 weeks after the separation starts, enough cells have died that a crack has formed. In a breeze, or because of its own weight, the leaf falls.



The abscission layer (left) forms layers of cork (center) which separate from the stem (right) leaving a leaf scar.

Most gymnosperms and a few other plants have **persistent foliage.** The leaves do not fall until the following spring when new leaves have formed. Since many persistent leaves retain their chlorophyll all year, the plant has an evergreen appearance.

The beautiful autumn colors seen in North America are evidence of the fact that even green leaves have other colored pigments in them. When the abscission layer begins to block the water supply, the leaf can no longer produce chlorophyll. As chlorophyll wears out and is not replaced, other pigments begin revealing magnificent yellows, oranges, reds, and purples.

In many leaves, anthocyanins are formed only in cool temperatures as the sun reacts with sugars that remain after the abscission layer has

formed. The brightest leaf colors, therefore, appear when the fall has sunny days with temperatures that dip to about 4° C (40° F). Cloudy, warm fall seasons in some parts of the world do not allow leaf colors to be as brilliant.

Some leaves do not produce these other pigments. When these leaves die, they appear a brownish color as even the most beautifully colored leaves do eventually. This coloring is due to *tannic acid,* the product of the chemical breakdown of plant cell contents. The large concentration of tannic acid found in some leaves is readily dissolved in water to form tea, the most widely consumed beverage in the world. Most other plant leaves also release tannic acid when they are placed in water, but many of them release poisonous or distasteful chemicals as well.

Plant Pigments

Carotenoids are fat-soluble pigments found in the plastids of some plants. *Carotenes* and *xanthophylls,* two types of carotenoids, account for the yellow or orange, as well as some red, colors in certain plants. Carotenoids are responsible for the pale yellow-green areas of leaves that are grown without sufficient light as well as the colors of such plant parts as daffodil flowers, carrots, pumpkins, and corn kernels. When found in conjunction with chlorophyll, some carotenes help capture light necessary for photosynthesis and somehow help protect chlorophyll from intense light. Since carotenoids are the basic substances from which our bodies form vitamin A, a balanced diet contains yellow or red fruits or vegetables.

Anthocyanins* (AN tho SY uh ninz) are red, blue, and violet water-soluble pigments found in the vascular sap of plant cells. Leaves of the scarlet maple and some variegated leaf plants like the coleus have large quantities of anthocyanins, which also color grapes, plums, cherries, geraniums, roses, orchids, beets, and radishes.

Answers–Review Questions 12B-2

1. **(a)** In pinnate venation, veins branch off one large central vein (midrib); in palmate, two or more main veins come from a single point. **(b)** A simple leaf has one blade on a petiole; a compound leaf has more than one blade (a divided blade on a single petiole). **(c)** A pinnately compound leaf has leaflets branching off the midrib; a bipinnately compound leaf has leaflets branching off secondary (or higher) ribs from the midvein.
2. Stomata are small openings on the underside of leaves. They permit gas exchange between the atmosphere and the

phloem of the stem. The large veins of a leaf contain thick-walled strengthening *collenchyma** (kuh LENG kuh muh) tissues around the vascular tissues. As the veins branch and get smaller, the amount of supporting tissue lessens. The smallest veins contain only a single xylem vessel. Xylem is necessary to conduct the water and dissolved minerals from the roots to the cells of the leaf. Every cell in the leaf is only a few cells away from the end of a xylem vessel. The sugars and starches made in the leaf pass by diffusion until they come to a phloem cell. The phloem then carries these leaf products to other areas of the plant for use or storage.

collenchyma: coll-, (with or together) + -en- (in) + -chyma (to pour)

Review Questions 12B-2

1. Differentiate between (a) pinnate and palmate venation; (b) simple and compound leaves; and (c) pinnately compound and bipinnately compound leaves.
2. Describe and give the function of the stomata of a leaf.
3. Draw and label a cross section of a typical dicot leaf.
4. Describe the process whereby leaves change color and fall in the autumn.
5. List and describe plant pigments often found in leaves. What accounts for the brown color of old leaves?

The Root

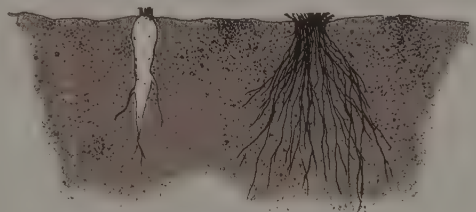
Most of us think of **roots** as the underground parts of plants. This is only partly true. First of all, not all roots are below ground. The roots of epiphytic orchids, for example, creep along tropical tree branches and obtain water and minerals from the materials that collect in cracks in the bark. The roots of parasitic plants such as mistletoe grow into the tissues of their host. Some aquatic plants have short roots dangling into the water from their floating leaves. Other roots, such as those in the ivy plant, hold the plant onto a rough surface like a brick wall.

Most roots serve to *anchor* the plant, even though they may not be in the soil. They *absorb* water and the dissolved minerals necessary for plant growth. Roots also *transport* these absorbed substances to where they are needed in the plant. Roots also function in *food storage* as with carrots, radishes, and beets.

Root systems

Plant roots differ greatly, depending not only upon the plant itself but also upon the conditions in which the plant is grown.

When the original root that sprouts from the seed, called the *primary root,* continues to grow as the predominant root, the plant has a **taproot system.** Not all taproots are fleshy, as are beets or carrots, but are often long and thin. They produce small, branching *secondary roots.* If the plant lacks a taproot but has many secondary roots, it has a **fibrous root system.**



taproot system   fibrous root system

Unless a plant is very slow growing or lives in very moist soil, its roots will need much more surface area than the leaves. Yet most root systems do not go deeper than 1-2 m (3-6 ft.) into the soil. The roots of some large trees, like the pecan, often are less than 1.5 m (5 ft.) deep but may spread in a circle 30 m (100 ft.) in diameter. An 8-year-old alfalfa plant less than 30 cm (1 ft.) tall may have roots that total 9 m (30 ft.) long. A 4-month-old corn plant may be over 3 m (10 ft.) tall and have more than 150 m (500 ft.) of roots.

Roots of a giant sequoia may spread through 50,000 cu. ft. of soil. An oak 10.6 m (35 ft.) tall may have a taproot half that length, but secondary roots that spread in a circle over 23 m (75 ft.) in diameter. Some trees have roots over 30 m (100 ft.) deep.

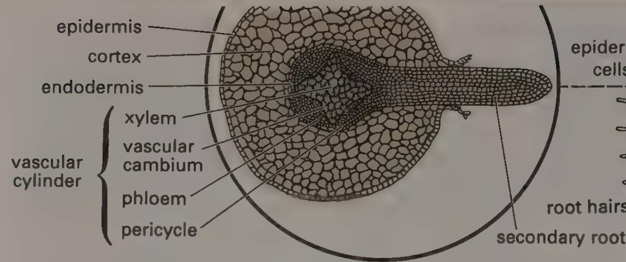
Primary growth of a root

If a root of a germinating seed is marked at millimeter intervals and then permitted to grow for 24 hr., the marks closest to the seed will still be

air spaces of the leaves. Stomata are regulated by guard cells.
3. See 12B-6 on p. 303.
*4. Deciduous leaves have a narrow, light-green abscission layer at the base of the petiole. This layer forms before the leaf is completely developed and is partly made up of cells which begin to die as the days shorten. The abscission layer also forms a layer of cork cells that seals the vascular tissues and forms a leaf scar on the stem. Approximately 2 weeks after the separation starts, enough cells die to form a crack; the petiole soon breaks from the stem due to wind or the weight of the leaf. When water is no longer available to the leaf, chlorophyll manufacture stops, and in time the other pigments of the leaf can be seen.
*5. The carotenes and xanthophylls, mostly yellow or orange colors, are carotenoids (fat-soluble pigments found in the plastids of some plants). They are responsible for the pale yellow-green areas of some leaves and the yellow-orange parts of several parts (flower petals, carrots, pumpkins). When found in conjunction with chlorophyll, some carotenes help absorb light energy and shield chlorophyll from intense light. Carotene is a precursor of vitamin A. The anthocyanins, the red, blue, and violet pigments, are found in the vascular sap of plants. In many leaves, anthocyanins are formed only in cool temperatures as the sun reacts with sugars that remain after the abscission layer has formed. Leaves that appear brown do so because of tannic acid, which is a product of chemical breakdown of the plant cell contents.

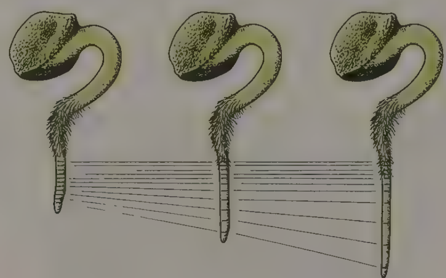
*From a box.

Visual 12B-5 can be used to teach the structures of a typical root tip. Markers are good for adding color, but to avoid confusion, do not use green.



a millimeter apart, but the second or third sections from the tip will be several millimeters apart. If the experiment is continued, the sections that expanded the most during the first 24 hr. will remain about the same length, but the section nearest the tip will continue to get longer. This growth in length is called **primary growth.** Why is primary growth found only in the tip of the root? Examining a longitudinal section of a young root under a microscope will provide the answer.

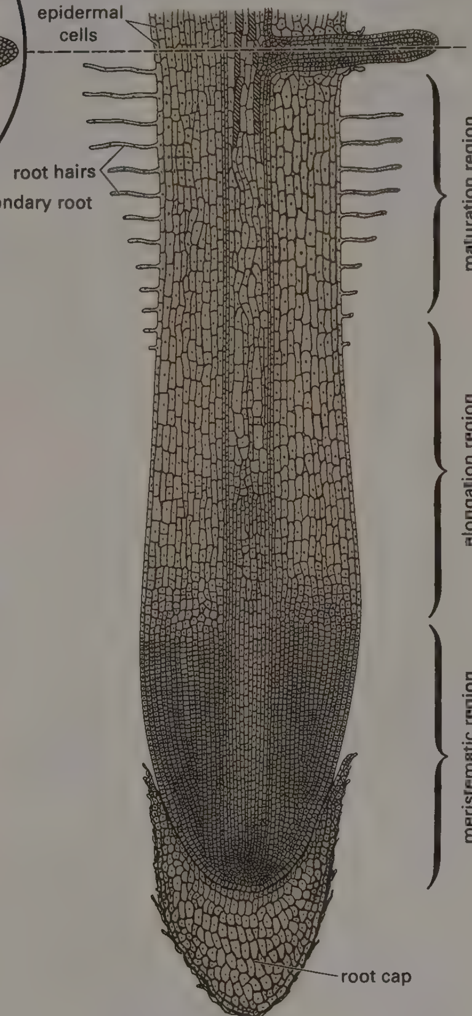
Carefully differentiate between primary and secondary growth and the tissues they form.



12B-7 Demonstration of the primary growth of a root

The tip of the root is covered by the **root cap,** made of dead, thick-walled cells which protect the delicate tissues of the root tip as it pushes through the soil. Just above the root cap is the **meristematic region,** where tiny undifferentiated cells carry on mitosis. The cells formed in the meristematic region begin to grow and establish large vacuoles in the **elongation region,** located just above the meristematic region. As the cells complete elongation, they begin to differentiate and become the tissues of a young root. The area where most differentiation takes place is called the **maturation region.**

The primary growth of a root results from the manufacturing of cells in the meristematic region. The actual lengthening of the root tip, however,



12B-8 *Longitudinal section of a root tip and a cross section of a young root*

is because of cell growth in the elongation region. Once the cells have elongated, they will not grow any more in length; hence, in the root marking experiment the marks closest to the seed will not be any farther apart, but the ones in the meristematic and elongation regions will be.

Modified Plant Parts

Not all plants have only typical leaves, roots, and stems. Many plants have modified structures that permit them to carry on unusual functions or thrive in areas where it would otherwise be impossible to grow.

Leaf modification

Leaves often perform some very interesting functions in addition to, and sometimes in place of, photosynthesis. Spanish moss (which is neither Spanish nor moss but is a member of the pineapple family)

has no roots but drapes gracefully on everything from tree branches to telephone poles by ''holding on'' with its leaves. The circular scales of the onion are underground storage extensions of the green leaves which carry on photosynthesis above the ground. The insect-catching apparatus of the Venus's-flytrap and the other insect-eating plants are modified leaves (see pages 321).

Some common leaf modifications are as follows:

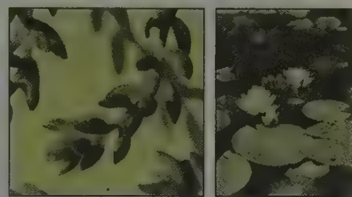
❑ **Tendrils** A plant part that wraps itself around something in order to help support the plant

may be called a tendril. Tendrils are often extensions of the midribs of compound leaves, as in the pea. They may be special leaves that lack blades, or outgrowths of the petiole, as in grapes.

❑ **Spines** Technically, a *spine* is a leaf, a *thorn* is a branch, and a *prickle* is an outgrowth of epidermal tissue. The terms are often

used interchangeably since they all refer to hard, sharp, usually nongreen plant protectors. A spine may be a tough petiole, as in the black locust, or a hard, sharp end of a vein, as in holly. Bladeless leaves of a cactus become dead spines which protect the thick photosynthetic stems.

❑ **Succulent leaves** Some plants store water in thick succulent leaves. Often the venation of these leaves is completely hidden. A succulent leaf usually has a tough cuticle and epidermal coating and, as in the aloe, is often edged with protective spines.



succulent leaves floating leaves

❑ **Aquatic leaves** Plants that live in the water often have leaves with enlarged spongy parenchyma which hold large quantities of air.

Primary tissues of a root

If you were to look at a cross section of a young root made just above the maturation region, you would see the **primary tissues.** Primary tissues are those which are made during primary growth. The outermost tissue, the epidermis, is one cell layer thick; it protects the root and absorbs materials. The epidermis in the maturation region produces cellular extensions called **root hairs.** These hairs penetrate between soil particles to water sources which would normally be out of reach for the root.

Just inside the epidermis is a layer of large, thin-walled parenchyma cells called the **cortex.*** In young roots the cortex stores materials. Inside the cortex is a single cell layer called the **endodermis.*** The small cells of the endodermis have walls which are bound to each other so that no material may pass between these cells. Substances must pass *through* these cells to enter the vascular

cortex: (L. CORTEX, bark or rind)

endodermis: endo- (within) + -dermis (skin)

This Facet contains interesting supplemental material. If time is short, it would be better to skim over some of the more technical parts of the chapter than to completely omit this Facet. Much of the material is simple enough that it will require only mentioning in class. Most of the modified plant structures listed here are found in the Biological Terms section at the end of the chapter. Be sure to tell students which ones they are expected to know for testing purposes.

If necessary, divide the covering of the material in this Facet, presenting each section while covering each plant organ.

Since the leaves of the water lily float, they have stomata on only the upper surface. *Elodea* and eel grass *(Vallisneria)*, common aquarium plants, have few stomata.

Since root hairs increase the absorbing surface of the root system as much as 20 times, the plant can obtain water even from seemingly dry soil. If they formed nearer to the root tip, they would be rubbed off as it moved through the soil.

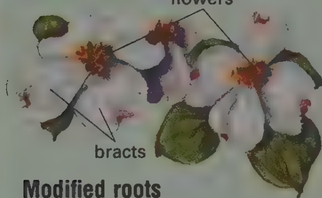
pericycle: peri- (Gk. PERI-, around) + -cycle (KUKLOS, circle)

The greater part of most edible storage roots, such as beets, carrots, turnips, and sweet potatoes, is composed of secondary tissues.

Some plants may have as many as 20 arms of xylem.

This stored air causes the leaves to float and supplies oxygen and carbon dioxide for respiration and photosynthesis.

❑ **Bracts** Some showy flowers lack petals but have brightly colored leaves called bracts. Often there are small flowers in the center of a group of bracts, as in poinsettias and flowering dogwoods.



Modified roots

Modified roots can be grouped into five categories:

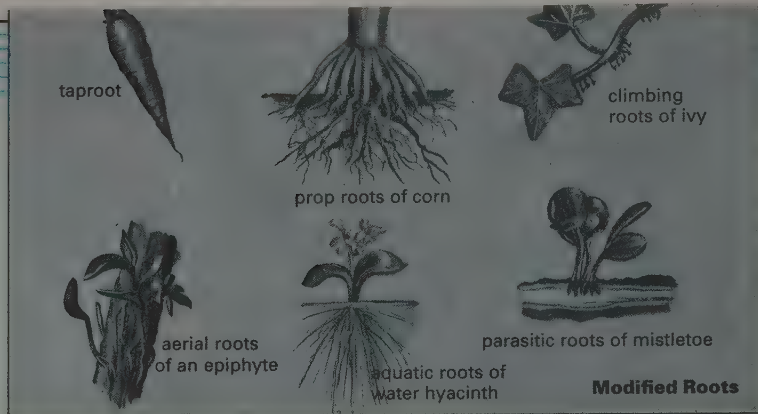
❑ **Storage roots** Thick and fleshy roots, usually containing starches and oils with pigments and other chemicals, are called storage roots. Taproots are often storage roots. These roots generally have secondary growth of xylem and phloem; and the pericycle, rather than producing cork, produces a thin layer of protective cells. When grown in temperate regions, most of our cultivated root crops such as carrots, beets, and radishes are annuals; however, they most often are hybrids of perennials with fleshy taproots similar to dandelion roots. Sweet potatoes illustrate another type of storage root. This plant produces fibrous roots which occasionally enlarge into fleshy sections.

❑ **Adventitious roots** Roots that grow from a stem, a petiole, or a leaf are called adventitious roots. They usually help anchor the plant. Adventitious roots that grow from the nodes of corn are called *prop roots.* Many vines have adventitious roots that sprout from the stems. These roots may support the plant by growing into the cracks of a structure and enlarging to fill the cracks. These are called *climbing roots.*

❑ **Aerial roots** Orchids, bromeliads, and other epiphytic plants have aerial roots. These roots not only anchor the plant and absorb water and minerals but also store water for dry periods. Some are green and carry on photosynthesis.

❑ **Aquatic roots** Roots which grow under water are called aquatic roots. They often lack root hairs but many of them have special tubes with the vascular tissues to permit gases to be exchanged in the growing parts of the root.

❑ **Parasitic roots** Roots of parasitic plants grow into the vascular tissues of the host plants and absorb water and dissolved minerals from the xylem. Some parasitic plants also absorb sugars from the phloem.



Modified Roots

tissues and pass to the rest of the plant. The endodermal cells insure that only certain materials are permitted into the plant.

The **vascular cylinder** is the central area of the young root. The center of the vascular cylinder in a dicot is the *xylem vessels.* In cross section the xylem in a dicot root often radiates four arms, but may have only two or three arms.

Between the arms of the xylem is the *phloem.* Between the xylem and phloem is the **vascular cambium.** This meristematic tissue can produce additional xylem and phloem. Between the vascular tissues and the endodermis is the **pericycle*** (PEHR ih SYE kul), which is also a meristematic tissue. If a secondary root is to be formed, it will originate in the pericycle and vascular cambium.

In monocots, pith is surrounded by vascular tissues. The vascular cambium is between the xylem and phloem. The endodermis separates the vascular cylinder from the cortex and epidermis.

Modified stems

Many common stems have various modifications, but because they are so common, most people do not recognize them as modifications. One easily recognized modification is the **succulent stems** seen in milkweeds and cacti. Succulent stems contain large quantities of water under thick cuticles and usually remain photosynthetic.

A number of different types of modified stems can be found underground. They are involved in producing leaves, keeping herbaceous plants alive over a period of years, and producing new plants.

❑ **Rhizomes*** (RYE ZOHMZ) are thick, fleshy, horizontal underground stems which produce leaves or leaf-bearing branches. Rhizomes of many plants, such as cattails, are edible. Rhizomes are found in many ferns, orchids, peonies, irises, and water lilies.

❑ **Stolons** are more slender than rhizomes, usually are much more branched, and produce secondary roots and aerial branches at nodes. Crabgrass, Kentucky bluegrass, and mints produce stolons.

❑ **Bulbs,** such as are found in onions, are actually collections of underground storage leaves branching from small discs of stems. Roots grow from the bottom of these stems. Other plants producing bulbs include the hyacinth, lily, daffodil, and tulip.

❑ **Tubers,*** such as Irish or white potatoes, are actually storage stems. Tubers produce roots and have "eyes" which are the nodes of these underground stems.

❑ **Corms** are thick underground stems that produce aerial leaves. A corm is often covered by several underground leaves. The solid fleshy tissue is a storage area which enlarges each year. Lateral buds form at the nodes of the corm, and additional corms are formed in successive years. Although we often say that gladioli and crocuses sprout from bulbs, they actually come from corms.

Review questions on page 310

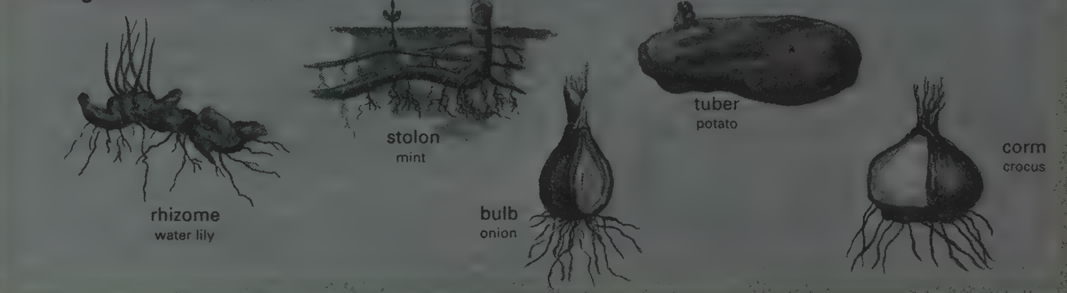
rhizome: rhi- (Gk. RHIZA, root) + -zome (body)

tuber: (L. TUBER, lump or swelling)

A common grasslike house plant, the spider plant, grows tubers which are excellent for demonstration purposes.

Rhizomes are commonly confused with roots but can be easily distinguished by their nodes and internodes.

Underground Modified Stems



Secondary growth of a root

When the primary tissue cells have enlarged as much as they can, growth in diameter stops. Typically, roots of monocot and herbaceous annuals grow no more in diameter; however other roots, especially those of woody plants, do increase in diameter by means of **secondary growth.** Any tissue that is manufactured following primary growth is called a *secondary tissue*. The vascular cambium produces *secondary xylem* around the core of primary xylem. *Secondary phloem* is also produced by the cambium.

Since there is no meristematic tissue to manufacture more cortex and epidermis, enlarging the vascular cylinder by adding secondary xylem and phloem crushes the cortex and epidermis. This destruction would leave the vascular cylinder exposed directly to the soil were it not for the *cork cells* produced by the pericycle. The thick-walled, dead cork cells seal the vascular cylinder so that

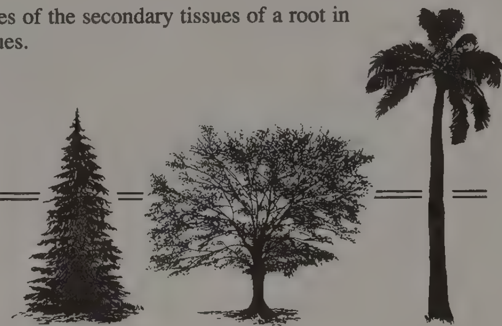
it cannot absorb water. Since absorption can now occur only through the epidermis near the tip of the root, the root must continue to grow in length if it is to continue to absorb water. Thus large perennial plants have extensive root systems to overcome this restriction in absorption of water.

Review Questions 12B-3

1. List the four primary functions of a root.
2. Describe the primary growth of a root. Use the names of the primary tissues of a root in your answer. Underline each of the primary tissues.
3. What is the function of root hairs?
4. Describe secondary growth of a root. Use the names of the secondary tissues of a root in your answer. Underline each of the secondary tissues.

Facet 12B-1: Modified Plant Parts, pages 307-9

1. List and describe five leaf modifications.
2. List and describe five common root modifications.
3. List and describe five common modified stems.



excurrent deliquescent columnar

The Stem

There are almost as many types of stems as there are types of plants. Above ground stems may be *erect* (as in trees and many flowers), or *climbing* (as in watermelons and cucumbers). Stems may be thin and herbaceous, as in most annuals, or thick and woody. Stems may be subterranean as in the cattail, Irish potato, tulip, and onion.

Most stems perform two major functions: they manufacture, support, and display leaves, and they conduct many of the materials needed for and manufactured by photosynthesis to and from the leaves. Most stems carry on photosynthesis when young; and in a few plants, like the cactus, even mature stems are the primary photosynthetic organs.

Branching Patterns

In stems there are three main branching patterns:

❑ **Excurrent** In plants such as pines and hollies, the apical bud of the main stem has dominance over the lateral buds. This **apical dominance** is exhibited in varying degrees, depending on the species. Apical dominance results in the **excurrent** branching pattern, usually forming cone-shaped bushes or trees with one main stem.

❑ **Deliquescent** Most angiosperms (like the apple, oak, maple, and many shrubs) have a **deliquescent** (DEL ih KWEH sehnt) branching pattern. In these plants apical dominance exists when they are young, but later the lateral buds become more active. When these plants are mature, it may be difficult to distinguish the main stem.

❑ **Columnar** Woody monocots and some dicots have **columnar** growth, which is typified by a crown of leaves atop an unbranched stem. Palm trees and many tropical plants exhibit columnar growth.

Dormant woody stems

If you look at the tip of a woody stem in a cross section, you can see a small meristematic area called the **apical meristem** (or *shoot apex).* Cells formed in this area of active cell division differentiate into leaves, stem tissues, and flowers.

Those woody stems that live through a winter period form **dormant buds** in the fall. The bud at the end of the twig is called the *apical bud.* Buds that form along the twig are called *lateral (axillary) buds.* Lateral buds usually develop only if the apical bud is damaged.

A cross section of a dormant bud reveals **bud scales** protecting tiny leaves and, if the tree is to bloom in early spring, flower parts. These leaves and flowers are formed in the autumn. In the

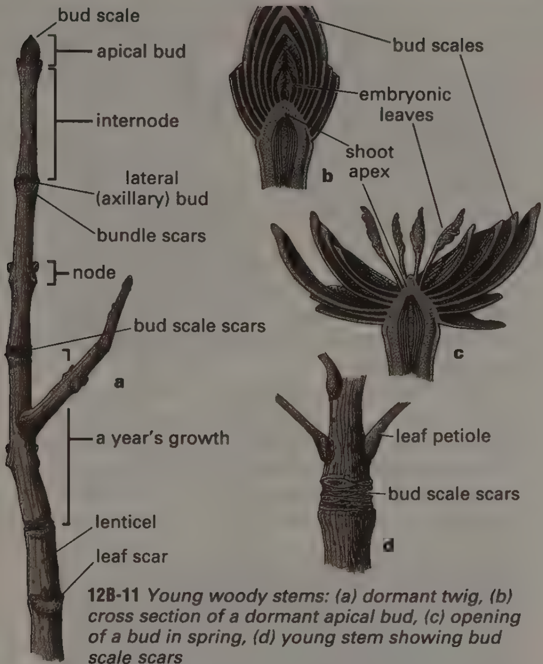
Observe dormant twigs. If possible, force some dormant flowering plants to begin flowering in class for observation.

Answers–Review Questions 12B-3

1. (1) Anchors the plant; (2) absorbs water and dissolved minerals; (3) transports absorbed substances; (4) stores food (carrots, radishes, beets)
2. Cell division in a root occurs in the meristematic region just above the root cap. This region, the area of primary growth, is composed of tiny, undifferentiated cells which undergo mitosis. The root cap cells also develop from the meristematic region and protect the delicate root tip. The elongation region appears just above the meristematic region and consists of meristematic cells which have begun to grow and establish large vacuoles. Elongation causes growth in root length. In the maturation region, cells complete elongation, begin to differentiate, and become tissues of a young root–*epidermis, cortex, endodermis, xylem, vascular cambium, phloem,* and *pericycle.*
3. Root hairs increase the surface area of the root epidermis for absorption of water and minerals. They penetrate between the soil particles to obtain water.
4. Secondary growth is growth in diameter. The *vascular cambium* produces *secondary xylem* around a core of primary xylem; *secondary phloem* is also produced from the vascular cambium.

Answers–Facet 12B-1

1. (1) Tendrils, which wrap themselves around other objects, often are extensions of the midrib of compound leaves; they may be leaves; they may be leaves which lack blades or outgrowths of the petiole. (2) Spines are hard, sharp, usually nongreen plant protectors and may be a toughened petiole or a hard, sharp end of a vein. Bladeless leaves of cacti also become dead spines which protect the photosynthetic stems. (3) Succulent leaves store water; often their venation is completely hidden; they have a tough cuticle and epidermal coating and are



12B-11 *Young woody stems: (a) dormant twig, (b) cross section of a dormant apical bud, (c) opening of a bud in spring, (d) young stem showing bud scale scars*

spring, water from the root causes these structures to expand to almost full size overnight. When the bud scales fall, they leave rings of *bud scale scars* around the twig. Since dormant buds are formed only in the fall, counting the terminal bud scale scar areas which completely encircle the twig enables you to determine its age.

If you examine a dormant twig of a deciduous plant, you will find the cork-covered **leaf scars.** The tiny dots within the leaf scar, called the *vascular bundle scars*, are where xylem and phloem went from stem to petiole. The shape of the leaf scars and the number and arrangement of the vascular bundle scars are so characteristic of a species that some botanists can identify trees by examining dormant twigs.

The places where leaves are produced on a stem are **nodes,** and the areas between nodes are called *internodes*. By examining the number of nodes and the length of internodes produced in a given year, you can determine how productive the plant was that year.

Structure and growth of woody stems

A cross section of a young stem reveals an exterior coating of *epidermis*. Most young stems have guard cells and stomata which permit the exchange of gases for photosynthesis. Just under the epidermis is a layer of **cork cambium** which will produce cork cells to protect the stem after it has grown too large for the original epidermal cells.

Inside the cork cambium is a layer of cortex, which stores materials and usually is photosynthetic. In older stems the cortex serves for storage but may eventually disappear completely. The phloem, with its strengthening *sclerenchyma** (skluh RENG kuh muh) fibers, is inside the cortex. A thin layer of meristematic cells called the vascular cambium separates the phloem from the xylem. Inside the xylem is the **pith,** the largest area of a young stem. The cells of the pith store and conduct materials. Spokelike **pith rays** extend from the central pith through the xylem and into the phloem areas.

In the first year little secondary growth takes place, but in the next growing seasons secondary growth in woody stems noticeably increases their diameter. Pith continues to be the most central tissue, but its diameter does not increase. *Vascu-*

Kinds of Wood

The central xylem of a mature woody stem is composed of dead cells that have been sealed off with tannins, gums, and other materials. This *heartwood* is often darker. The lighter *sapwood* is used in storage and is able to conduct water and dissolved minerals.

Wood varies in density, hardness, durability, strength, grain, and texture.

❑ *Hardwood* trees are usually angiosperms such as oaks, maples, walnuts, hickories, and cherries. Because of their strength and grain, hardwoods are used primarily for cabinets, furniture, veneers, tool handles, and musical instruments.

❑ *Softwood* usually comes from gymnosperms. Softwoods are easier to work with than hardwoods; but lack the strength, density, and beauty of the hardwoods. Softwoods, including firs, pines, spruces, and cedars, are used for construction, pulp, plywood, and pencils.

sclerenchyma: scler- or sclero- (Gk. SKLEROS, hard) + -en (in) + -chyma (to pour)

Use several small logs from various types of trees in the classroom. Try to use specimens common in the local area.

This box contains supplemental material that explains some commonly used terms in relation to their biology. Omit this box if time is limited.

There are no terms from this box listed in the Biological Terms list at the end of the chapter, but consider informing students that they need to know *heartwood, sapwood, hardwood,* and *softwood* for testing purposes.

An insect or fungus inside a tree can destroy the heartwood, which can cause the trunk to be hollow. Since the heartwood is dead, functioning only in support, the tree can still live but may eventually die of related causes.

Softwoods yield *oleoresin*, the raw material for the turpentine and rosin of commerce.

often edged with protective spines. (4) Aquatic leaves, leaves of water plants, often have enlarged spongy parenchyma tissues that hold large quantities of air; they may float as a result of stored air. (5) Bracts, which surround flowers, are brightly colored and may appear to be the flower petals (e.g., poinsettias, dogwood).

2. (1) Storage–thick and fleshy, storage of starches and oils; (2) adventitious–roots that develop from a stem, petiole, or leaf; (3) prop–type of adventitious root that grows from the nodes of a corn stem; usually anchors the plants; (4) climbing–type of adventitious root that grows from the stem to support the plant on vertical structures; (5) aquatic–roots of aquatic plants that lack root hairs
3. (1) Rhizomes–thick, fleshy, horizontal underground stems; (2) stolons–more slender and more branched than rhizomes; produce secondary roots and aerial branches at the nodes; (3) bulbs–actually short stems with many storage leaves; (4) tubers–actually storage stems; (5) corms–thick underground stems that produce aerial leaves

The length of vascular rays is extended by the vascular cambium.

lar rays, which permit the horizontal movement of water and dissolved substances, extend from the central pith region to the bark areas.

The vascular cambium produces secondary xylem and phloem cells. If the cell is on the inside of the vascular cambium, it will become xylem; if on the outer surface, it will become phloem. Xylem tissues are called wood. During a growing season the vascular cambium constantly produces new xylem. During the spring when there is abundant water, large xylem vessels are produced. Drier summers cause smaller xylem vessels to be produced. The larger vessels are called *springwood* and are lighter in color than *summerwood.*

When you look at a cross section of a woody stem, you see these layers of springwood and summerwood as **annual rings.** By studying annual rings, scientists can tell not only how old a tree is but also how the weather and other conditions have changed. Some trees produce more than one ring per year; in moist tropics growth rings may be poorly defined and often do not represent a year's growth.

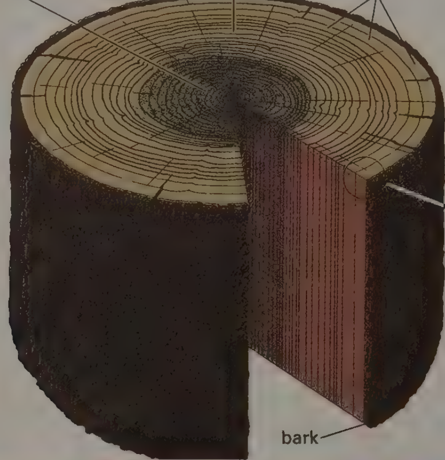
The growth of bark

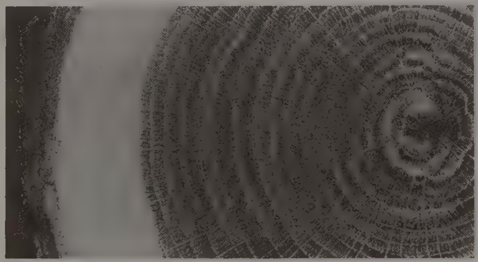
The vascular cambium produces phloem. Phloem is produced in much smaller quantities than xylem. Secondary phloem in woody stems is usually arranged as a ring of pyramids. Strengthening sclerenchyma is often found between the phloem pyramids. Phloem, its strengthening tissues, and the cortex comprise the **inner bark.**

The *cork cambium* produces flattened, thin-walled cells which fill with a fatty substance called *suberin.* These cork cells then die but are impenetrable to water, gases, and most parasites. Cork is continually produced by the ever-increasing circle of cork cambium. The cork, however, cannot expand along with the cork cambium. Therefore, as secondary growth continues, the outermost layers of cork split, forming the textured **outer bark.**

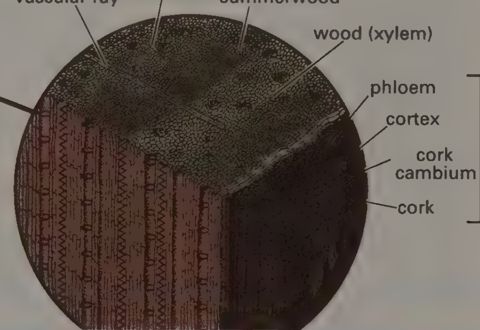
Different types of trees produce different types of outer barks. The white birch trees of Canada and the northern United States produce thin layers of white cork which peel off the trees. Oaks have thick, rough bark; maple bark is relatively smooth. Experts can determine the family, genus, and even species of a tree merely by examining

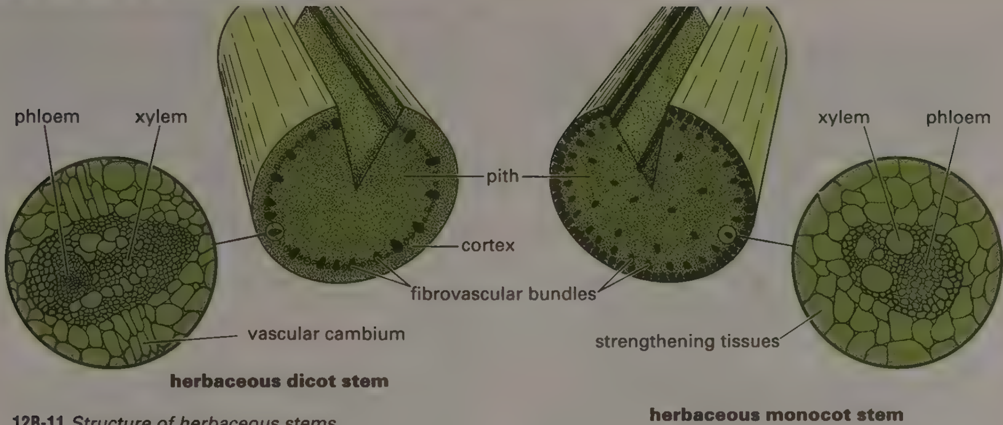
Visual 12B-6 can be used to teach the structures of a cross section of a mature woody stem. Markers are good for adding color, but to avoid confusion, do not use green.





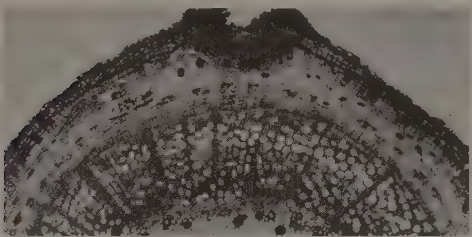
12B-10 *Cross sections of a mature woody stem. Can you find the structures that are in the photograph labeled in the drawing? How old is the tree in the photograph?*





12B-11 *Structure of herbaceous stems*

the outer bark. **Lenticels,** tiny openings in the cork layer of a mature woody stem, allow the stem to receive the oxygen necessary for respiration.



12B-12 *Cross section of a woody twig through a lenticle*

Herbaceous dicot stems

A typical herbaceous dicot such as clover, a marigold, or a daisy does not have a cork cambium and therefore will retain its epidermis throughout its entire life span. Its stem cortex is usually photosynthetic. The vascular tissues do not form continuous concentric circles, as in woody stems, but are arranged in **fibrovascular*** (FYE broh VAS kew lur) **bundles.** These bundles are usually located around the edge of the stem. Inside the fibrovascular bundle ring is the pith, which may contain chlorophyll and be photosynthetic, especially in young stems.

Secondary growth in herbaceous dicot stems is limited. Between the xylem and phloem of the fibrovascular bundles there usually is a layer of meristematic tissue which can produce secondary xylem and phloem. As the fibrovascular bundles grow, however, there can be little increase in the size of the epidermis since there is no meristematic tissue available to add to that made during

Girdling

The functions of the xylem and the phloem in a woody plant can be illustrated by **girdling.** If a strip of bark, including the vascular cambium, is removed from the trunk of a tree, the tree has been girdled. Sometimes gnawing animals or a chain will girdle a tree. Nutrients are still sent up the sapwood of a girdled tree; therefore, the top of the tree will continue to produce leaves and carry on photosynthesis. The trunk above the ring will continue secondary growth.

Below the girdled area, however, the trunk will not grow in diameter. Since the phloem cannot carry sugars produced in the leaves down to the roots, the roots are forced to use stored food to continue growing. As food reserves are depleted, roots will be unable to produce new roots and root hairs. This depletion also prevents water and dissolved minerals from getting to the leaves which will then wither. The tree finally dies because it cannot make its own food.

fibrovascular: fibro- (L. FIBRA, fiber) + -vascular (vessel)

Lenticels, products of the cork cambium, are composed of masses of loosely-arranged cells with numerous intercellular spaces that allow oxygen passage.

If time is limited, omit the material about herbacious stems or summarize it in a few brief statements.

Herbaceous stems are easy to illustrate: celery from the grocery, cut flowers from the florist, and cut stems of house plants can be stained with food coloring or ink to show the arrangement of fibrovascular bundles.

This box contains supplemental material that can be used to demonstrate the functions of the plant tissues described. Omit the box if time is limited.

There are no terms from this box listed at the end of the chapter, but consider informing the students that they need to know *girdling* for testing purposes.

The functions of xylem and phloem can also be illustrated by placing a cut branch in a solution of dye. A cross section will show that the wood cells have become stained. If the cut surface of a branch is covered with wax and placed in water, the leaves will wilt because of the obstruction of the vessels.

Answers–Review Questions 12B-4 *(p. 314)*

1. They manufacture, support, and display leaves. They conduct necessary materials to the leaves for photosynthesis and growth and to the roots for growth.
2. **(1)** Bud scales–protect tiny leaves in the dormant bud; **(2)** apical bud–dormant bud at the end of a twig; **(3)** internode–section of stem between two nodes; **(4)** lateral (axillary) bud–dormant bud along the twig; superior to the bundle scar; **(5)** bundle scars–tiny dots where xylem and phloem went from stem to petiole; **(6)** node–place on a stem where leaves are produced; **(7)** bud scale scars–markings left by bud scales; **(8)** lenticel–tiny openings in stem for gas exchange; **(9)** leaf scar–where petiole of a leaf was attached to stem
3. Secondary growth in a stem results from mitosis in the vascular cambium. Phloem cells form on the outer surface of the vascular cambium, and xylem cells form the woody tissue.

*4. **(a)** Heartwood is dead xylem cells that are often darker than sapwood; sapwood is xylem cells that conduct water and minerals. **(b)** Springwood is xylem cells that develop early in the growing season; the cells are large with thin walls; summerwood is small, thick-walled xylem cells that develop later in the growing season. **(c)** Hardwood comes from slower growing angiosperms; softwood comes from faster growing gymnosperms.

5. The cork cambium produces flattened, thin-walled cells that fill with suberin. These cells die and form the outer bark. The inner bark consists of phloem, various strengthening tissues, and some cortex tissue.
6. Similarities: **(1)** Both have fibrovascular bundles. **(2)** Both have pith in the center.
   Differences: **(1)** Monocot stems lack meristematic tissue (except in the

primary growth. Some large herbaceous dicots split their epidermis and rely on secondary strengthening tissues around the fibrovascular bundles to protect their stems.

Except at the nodes, monocot stems generally lack meristematic tissue. Secondary growth, even in "woody" monocots, is limited. The slender columnar growth of palm tree trunks is an example of this. Herbaceous monocots, like corn and grass, have fibrovascular bundles which, when cut in cross section, usually reveal a "monkey face" of xylem, phloem, and strengthening tissues. These fibrovascular bundles are scattered throughout the pith of the stem. In some monocots, like bamboo, the central pith disappears, leaving a hollow mature stem.

Biological Terms

vegetative organ
reproductive organ
meristematic tissue
vascular tissue
xylem
annual plant
biennial plant
perennial plant
phloem
structural tissue

The Leaf

blade
petiole
stipule
leaf venation
parallel venation
netted venation
pinnate
palmate
leaflet
epidermis
cuticle
stomata
guard cell
parenchyma
palisade mesophyll
spongy mesophyll
deciduous
abscission layer
persistent foliage
carotenoid
anthocyanin

The Root

root
taproot system
fibrous root system
primary growth
root cap
meristematic region
elongation region
maturation region
primary tissue
root hair
cortex
endodermis
vascular cylinder
vascular cambium
pericycle
secondary growth

The Stem

apical dominance
excurrent
deliquescent
columnar
apical meristem
dormant bud
bud scale
leaf scar
node
cork cambium
pith
pith ray
annual ring
inner bark
outer bark
lenticel
fibrovascular bundle
girdling

Facet

tendril
spine
aquatic leaves
bract
storage root
adventitious root
aerial root
aquatic root
succulent stem
parasitic root
succulent leaves
rhizome
stolon
bulb
tuber
corm

Review Questions 12B-4

1. What are the major functions of a stem?
2. Describe a dormant twig. Tell the functions of each structure.
3. Describe secondary growth in a stem.
4. What is the difference between (a) heartwood and sapwood; (b) springwood and summerwood; and (c) hardwood and softwood?
5. Describe the formation of bark.
6. List two differences and two similarities between herbaceous monocot and herbaceous dicot stems.

Thought Questions

1. Why is it essential that every cell in a leaf be near a xylem vessel, while it is not essential that every cell be near a phloem tube?
2. Roots must continue primary growth even though the plant is well anchored. Why?
3. What types of plants have fewer than an average number of root hairs?
4. What can and cannot be determined about a tree by examining its annual rings?
5. Compare and contrast (a) the primary growth of a stem and a root and (b) the secondary growth of a stem and a root.

Answers begin on page 313.

apex), while dicot stems have meristematic tissue between the xylem and phloem of their fibrovascular bundles. (**2**) Dicot stems have fibrovascular bundles in a ring, while monocot stems have fibrovascular bundles scattered throughout the cortex.

Answers–Thought Questions

1. Most cells in the leaf contain chloroplasts and perform photosynthesis; so they have an ample supply of dissolved foods and do not depend upon the phloem. However, the xylem transports nitrates, magnesium, and other minerals that are needed for photosynthesis; so each photosynthetic cell must be near the xylem.
2. They must continue to obtain water and minerals for the growing aerial portion of the plant.
3. Aquatic plants and plants that have mycorrhizae growing on roots to function as root hairs would need fewer root hairs.
4. Its annual rings may be used to determine its age and also the related weather conditions for each year. The annual rings do not provide information about its vertical height.
5. (**a**) Primary growth of a stem (which is growth in length) develops from the shoot apex at the base of the terminal bud. Primary growth in a root develops from the meristematic region immediately inside the root cap. (**b**) Secondary growth (growth in diameter) in woody stems and roots is accomplished by mitosis in the vascular cambium.

THE LIFE PROCESSES OF PLANTS
BOTANY PART II

THIRTEEN

Time Frame
13A (with Facets): 2 periods
13B (with Facets): 1-2 periods

Laboratory Activity
13–*Flowers, Fruits, and Seeds* is an easy laboratory activity which can be done in a single class period. Sections of the activity can be done as demonstrations of the class lecture, thus cutting down the amount of time the laboratory activity will take.

13A–Plant Physiology

Although plants require basically the same materials, various plants must have them in different amounts to grow properly. A corn plant requires 135-180 kg (about 300-400 lb.), which is 150-190 liters (L) (40-50 gal.), of water in a growing season, but a healthy desert cactus may not get that much in 10 yr. If the corn were transplanted to the desert and the cactus to the field, one would quickly wither, and the roots of the other would rot. Cypress trees grow best in flooded areas, but a palm tree could not grown there. A forest floor fern, if transplanted into a meadow, would get too much sun and die. A meadow fern transplanted to the forest would also die but for the opposite reason.

Not all the areas of the world were designed to have the same conditions. God designed the plants to have specific sets of requirements. Thus plants *grow* best in certain areas, *survive* in some places, and *do not tolerate* other conditions.

We would think it foolish if someone planted a banana grove in northern Canada. He would be

13–Botany Part II: The Life Processes of Plants

According to many people, the more interesting botanical material is found in this chapter. Chapter 13A deals with plant physiology: what plants need to grow and what affects their growth. Chapter 13B deals with flowers, fruits, seeds, and germination.

It is suggested that detail be avoided in these chapters. Do not have students memorize the minerals a plant absorbs from the soil, the names and functions of nuclei in pollen grains, or the details of the double-fertilization process in plants. These topics are briefly covered in this chapter, and some teachers may want to go into detail with advanced students or situations involving multiple years of biology. Other teachers will want to expose their students to some of this material and not expect them to master much, if any. Some teachers will have their classes read this material but will not mention it in class. Others may decide to omit it.

Questions that reflect an understanding of the double fertilization of plants, a knowledge of how water travels in a stem, and what minerals a plant needs often may appear on standardized tests. These items appear to be the information well-educated biology students know, but the students who have merely taken a science class and gotten passing grades (by the teacher's grace) do not know. Good arguments could be made against this position. But that does not change what is on standardized tests.

Carefully select what sections to have the students read, what to teach, to skim, to hold the students accountable for, or to omit. (There are suggestions in the marginal notes of the chapter.) Then adjust the time frame accordingly. Be sure to tell students what is expected of them.

humus: (L. HUMUS, soil)

The availability of water and oxygen must be balanced in soil for plant growth. Clay soil will retain 3-6 times more water than sandy soil, but pure clay soils are not well suited for plant growth. Clay particles are generally so tightly packed that the roots cannot obtain enough oxygen from the pore spaces.

Consider a demonstration of funnels filled with sand, silt, gravel, and clay. Pour the same amount of water into each one and catch the water in a measuring device. The larger the particles, the faster the water will come through.

Some of the terms regarding water are illustrated on page 458.

Visual 13A-1 can be used as an outline to teach the components of soil and kinds of water in the soil.

Use this table as an outline for teaching this material.

ignoring either the Canadian weather or the requirements of banana plants. A farmer must consider all the environmental conditions of his farm before he plants a crop, or he may experience a crop failure. Even when a person selects a plant for his yard or his room, he should consider the conditions available to the plant.

Plants and Water

Plants contain large amounts of water. If 10 g (0.35 oz.) of grass is dried, it weighs only 3 g (0.1 oz.). Most herbaceous parts of plants are over 80% water. Plants also require large amounts of water. An acre of rapidly growing corn gives off 1,000,000 L (250,000 gal.) of water per day. A single large oak tree may lift 1,000 L (250 gal.) in 24 hours.

Plants use water for several purposes:

❑ *Photosynthesis* For each molecule of glucose made by plants, 6 or more molecules of water must be broken apart.

❑ *Turgor* The abundant presence of water in the cells stiffens the herbaceous parts of plants.

❑ *Hydrolysis* Plants often break apart large molecules by adding water molecules or parts of water molecules.

❑ *Translocation* The materials in a plant can be moved only if they are dissolved in water.

Water in the soil

Most plants cannot absorb the water that falls on or collects on their leaves. The leaves, however, often are arranged so the water falling on them will drop to the soil in the area of the roots of that plant. The root tips then absorb the water.

Soil texture, the size of the particles in the soil, is a major factor in the amount of water that soil can contain. The inorganic components of the soil that affect soil texture are *gravel, sand, silt,* and *clay.* A mixture of sand, silt, and clay is called **loam.** An ideal loam is considered to be 40% sand, 40% silt, and 20% clay. Loams that vary from this ratio are called sandy loams, clay loams, and silt loams, according to their major component.

Topsoil is composed of loam, living organisms, and **humus*** (dead organic matter). Soil is not "dead"; living organisms make up about 10% of the weight of good soil. They break down such things as fallen leaves and dead animals (humus), as well as inorganic substances (loam particles), into absorbable materials that plants can use.

Inorganic and organic components of the soil determine the size and quantity of **pore spaces.** The ability of the soil to contain water and air is determined by the pore spaces. Small soil particles have less space between them; therefore, soils with high concentrations of smaller particles, such as clay, absorb water slowly but remain moist for a long time. Sandy soils, on the other hand, accept water rapidly, but the water quickly passes through, and the soil soon becomes dry.

Some people think that plants will grow well if the roots are kept in water. Like other living tissues, however, the roots of a plant must have oxygen to carry on cellular respiration. Plants cannot use oxygen dissolved in water or oxygen in water molecules; therefore, most plants will die if their roots remain submerged. Those plants that naturally grow underwater have tubes which transport air down from their aerial parts or oxygen from the photosynthetic parts down to the roots. Most plants, however, lack these structures.

Water in the Soil

Runoff: Water which does not enter the soil (unusable to plants)
Gravitational: Water which is pulled through the soil to the water table (unusable to most plants)
Capillary: Water which is held between particles of the soil (absorbed by plants)
Hygroscopic: Film around soil particles after capillary water is gone (unusable to plants)

If water comes more quickly than it can be absorbed by the soil, it either collects in puddles or flows downhill. This is called *runoff water.* The water that goes into the soil may pass through the soil to an impenetrable layer (rock), accumulating to form the *water table.* This is *gravitational water* and is out of reach for most plants. Some plants, however, do send taproots down to the water table. The water in the pore spaces of the soil is called *capillary water* and is the water

13A–Plant Physiology

Notes–Chapter 1A

This chapter answers most of the usual student questions about plants. Have specimens to show plant responses and activities. A prayer plant (a common house plant) or a sensitive plant (easily grown from seed) can nicely illustrate nastic movements. A Venus's-flytrap in the classroom is a good attention getter. Dieffenbachia (dumb cane, a common house plant that comes in many varieties) can be made to guttate. Growing pea, corn, or bean seeds in normal light and in the dark to show etiolation is very easy.

Objectives–Chapter 13A

- ❑ List and describe the normal components of soil.
- ❑ List and describe a plant's uses of water.
- ❑ Describe how roots absorb water and minerals.
- ❑ Explain translocation of water, minerals, and food in a plant.
- ❑ Explain how various environmental factors affect plant growth.
- ❑ Describe how hormones affect a plant. List several plant hormones and tell their specific function in a plant.
- ❑ Distinguish between tropisms and nastic movements.
- *❑ List and describe several insectivorous plants. Discuss the value they receive from digesting insects.
- *❑ Explain the value of a plant's dormancy. List several mechanisms for breaking dormancy.

*From a Facet.

which plants absorb. Even when the soil is dry to our touch, there is still a thin film of water around many soil particles. Plants cannot use this *hygroscopic water*.

Water absorption

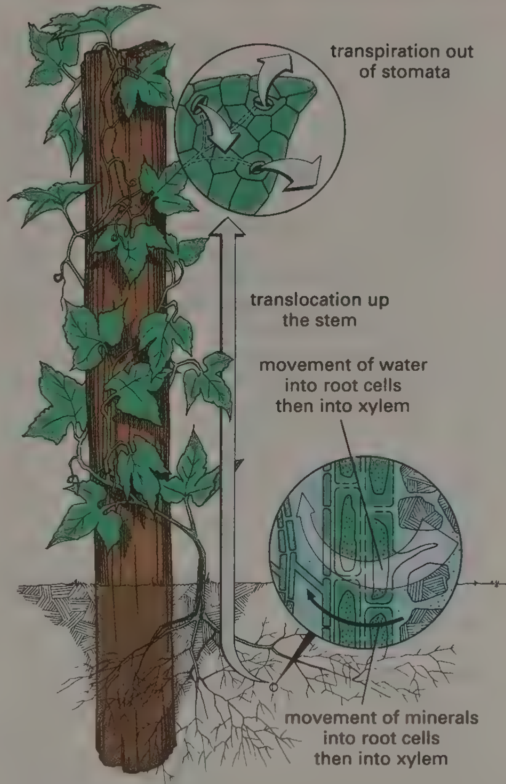
When there is a good supply of water in the soil, water is taken into the root hairs. The concentration of water molecules is higher outside the cell, and the concentration of solutes is higher inside the cell. This concentration gradient permits the movement of water molecules across the root cell membranes by osmosis. The concentration gradient must be set up by the cell, and the cell *expends energy* to maintain the higher concentration of solutes inside. These absorbed water molecules pass into the cells of the cortex and then to the vascular cylinder.

As more water enters the roots and collects in the vascular cylinder, pressure builds up. This is **root pressure.** This causes a movement of water (and dissolved minerals) up the xylem of the stem. If the stem of a well-watered plant is cut, drops of water will ooze from the vascular tissues as a result of root pressure.

Most of the water a plant uses, however, enters by a second method. When a plant is growing and carrying on photosynthesis, water is drawn away from the roots by the upper parts of the plant, and the cells in the root lose their turgidity. As the water concentration in the root cells lowers, water molecules are drawn into the cells. This process is called **passive absorption** because root cells do not expend energy to make it happen.

Translocation of water

The movement of water and dissolved minerals within a plant is called **translocation.** In small plants it is possible for osmosis and diffusion to move the necessary water and minerals. Indeed, this is the only method possible in bryophytes since they lack vascular tissues. It is also possible to assume that root pressure would be great enough to force water up the vascular tissues of small tracheophytes. Root pressure is rarely more than a fraction of a kilogram per square centimeter. Dozens of kilograms per square centimeter would be necessary to force water up plants that are over a meter tall. **Capillarity** (KAP uh LEHR ih tee) is a property of water that, at one time, was considered a possible explanation for translocation. Water rises slightly on the surfaces of its container. Operating according to the same principle by which water is absorbed into a paper towel, water will rise in a thin tube. The thinner the tube, the higher the water will rise. But even tubes as small as xylem vessels cannot produce capillary action to the height of tree leaves.



13A-1 *Transpiration-cohesion theory*

Although the forces of passive absorption and capillarity help to move water in a plant, most biologists support another theory of translocation. This theory is based on two considerations.

❑ **Transpiration*** Water is constantly evaporating from the leaves of a plant. This release of

transpiration: trans- (across) + -spiration (L. SPIRARE, to breathe)

The permanent wilting percentage of soil is the amount of water a soil contains when a plant can no longer absorb water from it. This percentage is lower if the plant is designed for an arid region.

Consider a demonstration of the conduction of substances up a stem using dyes (or ink) and white carnations or a young stem of celery. It may take a few hours, even overnight. Set up the demonstration one day and observe it the next.

Transpiration causes much of the coolness in a shady forest.

Keep the pace of the class moving along. If this material drags, boredom, discipline problems, or classroom naps (with or without closed eyes) can result.

Facets–Chapter 13A

The Facet on insectivorous plants can easily be summarized in a few statements. It contains information that many students find interesting. The Facet on plant dormancy also can be interesting and easily covered in a few minutes in class.

guttation: (L. GUTTA, drop)

Water cohesion is, in part, due to the tetrahedral structure of the water molecule. Each forms hydrogen bonds with 4 other molecules, holding water together with tremendous strength. The only liquid with greater surface tension is mercury.

The *Nastic Movements* box contains supplemental material which should be studied by most students. Omit this box if time is limited.

The term **nastic movement** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Other flowers that open and close with nastic movements are the crocus, tulip, California poppy, and dandelion.

The *Guttation* box contains supplemental material which should be studied by most students. Omit this box if time is limited.

The term **guttation** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

Strawberry plants and Dieffenbachia often guttate. Some grasses guttate at the tip of the leaf.

water vapor into the atmosphere is called transpiration. For example, a typical maple tree absorbs 361 kg. (800 lb.) of water in a day; but only 0.36 kg (0.8 lb.) of this water are used by the tree; the rest (799 lb.) passes out the stomata. A single mature oak tree may release 1,100 kg. (2,420 lb.) of water on a hot summer day.

❑ **Cohesion** The property of water molecules that causes them to "stick together" is cohesion. This is why water forms beads on a smooth surface and why there is enough surface tension for a needle to float on water.

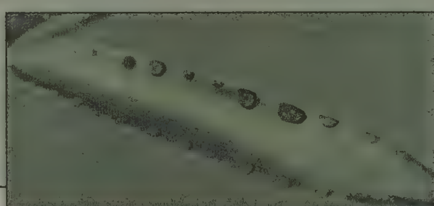
Today most scientists believe that water moves up a plant according to the same principle you use to drink with a straw. As molecules are removed from the top, additional molecules rush in at the bottom. This method of translocation in plants is called the **transpiration-cohesion theory.** The release of water by the leaves which causes water to come up from the roots and the tendency for water molecules to stick together are considered the best available explanations for the movement of water from the soil to all the leaves of a tree.

Turgor pressure and wilting

Most of the water that comes up a stem is given off as water vapor in transpiration. The second

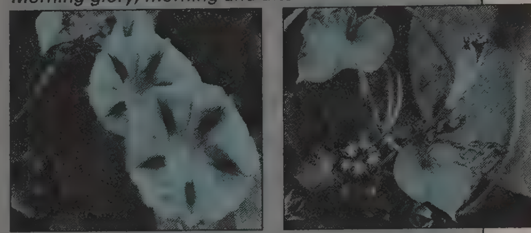
Guttation

Most of the stomata of a leaf are closed at night. In some leaves the stomata at the ends of veins or along the margin of the leaf do not close. When soil moisture, humidity, and temperature are right, these leaves may guttate. In **guttation*** (guh TAY shun), drops of water are forced through the stomata at the margin of the leaf. Guttation is not dew; dew comes from condensation of water vapor in the air. Guttation water originates in the roots and therefore, unlike dew, has dissolved minerals in it.



Nastic Movements

Morning glory, morning and afternoon



Prayer plant, day and night

Most of us have noticed that tulips, morning glories, buttercups, or similar flowers open during the day, close in the evening, and reopen the following morning. These are examples of **nastic movements.** Nastic movements in plants are caused by the loss or gain of turgor in certain cells, often at the base of the petal or leaf.

Since nastic movements depend on the presence or absence of water, they are temporary, reversible changes. For example, the sensitive plant folds its leaves by nastic movements in response to touch. A few moments after the leaves have collapsed, they will reopen.

Some nastic movements are based on the direction of light. The leaves of wild lettuce and the disc of the sunflower follow the sun as it crosses the sky. Some nastic movements may appear to be triggered by internal factors when they actually are controlled by some yet unexplained factor within the plant. The prayer plant, a common houseplant, folds its leaves at night (after sunset); however, putting a prayer plant in darkness will not cause it to fold its leaves until its usual time (after sunset). If the plant is placed in an area of constant temperature, humidity, and dim light, it will still open and fold its leaves by its usual schedule, not in response to a man-made environment.

Answers–Review Questions 13A-1

1. God designed plants to grow under specific conditions; water, light, heat, and mineral requirements vary for different plants.
2. **(1)** Photosynthesis (required reaction for glucose synthesis); **(2)** turgor (proper pressure to maintain shape and support of cell); **(3)** hydrolysis (breaking apart materials); **(4)** translocation (transport of dissolved substances)
3. Clay
4. **(1)** The inorganic parts of the loam (sand, silt, or clay) affect the texture of the soil, determining the size and quantity of pore spaces. **(2)** Living organ-

major use of water is maintaining turgidity. **Turgor** is the presence of water inside a plant cell in sufficient quantity to give the cell stiffness (see page 80). As long as there is sufficient water available to living cells, they will remain turgid, and the plant will be stiff.

During hot conditions a lack of water in the soil can cause *temporary wilting*. The closing of the stomata stops as much transpiration as possible, but there is still a loss of water into the environment. The loss of water reduces turgor, which causes the herbaceous parts of the plant to droop. Normally temporary wilting is corrected during cooler conditions when transpiration slows down or when the plant is watered.

Occasionally insects, fungi, or other factors damage vascular tissues and cause *permanent wilting*. Permanent wilting can also happen when the available water in the soil is exhausted and not replaced before the tissues die. During transplanting, the root tips can be destroyed, causing permanent wilting.

The Bible refers to the Word of God as the water whereby a Christian grows. If we do not keep ourselves rooted in the Word, our spiritual lives will wilt. In John 4 the woman at the well desired that Christ give her the living water so that she would never thirst again. That living water which keeps our spiritual lives full is available to us all.

When the leaf of the sensitive plant is touched, water leaves the cells at its base and passes into intercellular spaces, causing the petiole to move downward. Turgor is gradually regained, and the petiole resumes its position. Sensitive plants can easily be grown from seeds in the classroom.

Review Questions 13A-1

1. Why will all plants not grow equally well in the same conditions?
2. What are the four main uses of water in plants?
3. A plant that grows best when its roots are in moist soil would thrive best in a loam with a higher percentage of what soil component?
4. List the components of a good topsoil. Tell the significance of each component.
5. What four types of water will be found in or on the soil after a rain? Tell the significance of each in relation to the supply of water to plant roots.
6. Why are root pressure and capillarity inadequate to explain the translocation of water in a stem? Name and explain the method of translocation most botanists agree happens in plants over a few centimeters tall.
7. Compare and contrast temporary and permanent wilting.

Plants and Minerals

For centuries man has known that plants absorb materials from the soil. If a particular type of plant is grown and harvested repeatedly in a field, the yield decreases year by year as the necessary materials are depleted. It was once believed, therefore, that plants ate soil, much as animals eat food. Even today we speak of "plant food."

Except for a few parasitic and saprophytic plants, plants do not "eat food." Plants do *absorb soluble minerals* from the soil and use them to manufacture substances. The sun, however, is the energy source for food manufactured in plants.

Minerals in the soil

The known essential nutrient elements for plants are listed in figure 13A-2. Different plants require different amounts of these elements. Nitrogen may be 1-3% of the dry weight of a plant, potassium from 0.3-6%, and calcium as low as 0.1% or as high as 3.5%. Most minor essential elements and elements found in only a few plants are mere traces of the dry weight of the plant.

Plants are not always able to use an element in its free state. Nitrogen, for example, is a major component of the air. Plants cannot, however, use atmospheric nitrogen. Plant roots absorb nitrogen in the form of nitrates or ammonium ions.

In the American colonial period and the period of westward expansion, farmers did not replenish the minerals removed from the soil by crops. This was partly because most farmers did not know how to care for the land and also because they did not need to. There was still plenty of unfarmed land to use when an area "wore out."

Aristotle taught that the soil constituted a vast "stomach" which digested food prior to its absorption by roots, just as the digestive organs of an animal prepare food for assimilation into the body.

isms compose 10% of the weight of topsoil; they break down organic material (humus) and inorganic substances of the loam into absorbable materials that plants can use. **(3)** Humus (dead organic matter) can be broken down by living organisms to release usable materials for plant growth; it also helps determine size and quantity of pore spaces, which determine the amount of water and air contained in the soil. (Water and air are sometimes listed as components of topsoil.)

5. **(1)** Runoff water is not absorbed by the soil and is unusable to plants. **(2)** Gravitational water is pulled through the soil to the water table; it is unavailable to most plants, but some plants absorb this water through the roots. **(3)** Capillary water is in pore spaces of soil; it is absorbed by plant roots. **(4)** Hygroscopic water is a thin film of water on soil particles; it is unusable to plants.
6. Root pressure is not great enough to force water upward in plants over a meter tall. Capillarity will not draw water up the height of tall plants such as trees. It helps in translocation of water, but cannot account for all of it. According to the transpiration-cohesion theory, water constantly evaporates from leaves, drawing more water from the roots; the tendency for water molecules to stick together (cohesion) provides the pressure necessary to move water from the soil to the top of the plant.
7. Temporary wilting results from lack of water in the soil (e.g., a hot afternoon); the loss of water creates a loss of turgor, and wilting occurs. This is usually corrected naturally during cooler evenings when transpiration slows down or when the plant is watered. Permanent wilting is due to destruction of vascular tissues by insects or fungi or to tissue death from lack of water.

Tell the students not to memorize this table but to use it as a reference.

13A-2	Elements Needed by Plants	
Nutrient Elements	**Deficiency Symptoms**	**Some Functions**
Major Essential		
Nitrogen *Nitrates* $(NO_3)^-$ or *Ammonium* $(NH_4)^+$	Light green to yellowish lower leaves; little growth	Amino acids, proteins, nucleic acids, chlorophyll, coenzymes
Phosphorus *Phosphates* $(H_2PO_4)^-$ or $(HPO_4)^{-2}$	Dark green to purplish leaves; stunted growth	Formation of ATP, nucleic acids, formation of some fats, coenzymes
Potassium K^+	Yellowish leaves, turning brown at margin; weak stems	Protein synthesis, cell membranes, nucleic acids
Sulfur *Sulfate* $(SO_4)^{-2}$	Yellowing of young leaves	Some proteins, amino acids, coenzymes
Calcium Ca^{+2} (lime)	Disintegration of young shoots and root tips	Cell walls, aids in regulation of the uptake of other elements
Magnesium Mg^{+2}	Death of leaves from the base of the stem up	Chlorophyll, needed for some enzyme actions
Iron Fe^{+2} or Fe^{+3}	Gradual yellowing of leaves between small veins, then between larger veins	Chlorophyll formation, part of many enzymes
Minor Essential		
Boron, Manganese, Chlorine, Molybdenum, Copper, Zinc	Stunted growth or poorly formed plant parts, especially flowers and fruits	Primarily serve as activators for enzymes; other functions unknown
Found in Some Plants		
Aluminum, Silicon, Cobalt, Sodium, Selenium	Stunted growth or poorly formed plant parts	Various functions in plants specialized for certain environments; other functions unknown

The nitrogen cycle is discussed and illustrated on page 470.

Fertilizer is not a recent development. The Pilgrims were taught by the Indian Squanto to fertilize corn by placing the kernels near the fish heads placed in the ground. He also warned them to guard the crop for about 2 weeks until the fish rotted; otherwise, wolves would smell the fish and dig them up.

Active transport is discussed on page 88.

In the Southeast, cotton was the major crop prior to this century. Cotton, however, rapidly depletes the soil of nitrogen. Since fertilizing large areas of the major plantations was almost impossible at the time, farmers planted legumes such as peas, beans, and peanuts. These plants grow well in nitrogen-poor soil. Legumes also produce nodes on their roots which contain *nitrogen-fixing bacteria.* These bacteria take atmospheric nitrogen and add it to the soil as a nitrate, a form of nitrogen that plants can use. Farmers discovered that after a few years of planting legumes, they could again grow cotton successfully. Today *crop rotation* is one method of keeping a mineral complement in the soil.

Today a farmer can have his soil tested to learn what elements it contains. He can also learn what elements are needed by the various plants he wishes to grow. If his soil lacks a particular material, he can add chemical **fertilizers** to the soil. Often the contents of a container of fertilizer are expressed by three numbers, such as 10-10-10. The first number is the percentage of nitrogen; the second, phosphorus; and the third, potassium. Other elements may also be listed. In this way, a farmer adds only the needed minerals to his soil.

A third method of replenishing the minerals in the soil is by adding decomposing organic matter, often called **mulch.** This method builds and maintains the soil naturally. Cultivation often removes the leaves and other materials that would normally become mulch; organic debris can be added after cultivation to replace depleted substances. Adding mulch to cultivated soil also increases the size and number of pore spaces.

Absorption of minerals by roots

Nutrient minerals reach roots in a soluble form. The concentration of solutes is greater in the cell cytoplasm than in the water around the root cells. The cells must expend energy to move these substances in the cells against the concentration gradient. This *active transport* can be demonstrated

13A-1

Facets of Biology

Plants That Catch Insects

There are approximately 450 varieties of **insectivorous*** (IN sek TIV ur us) **plants,** plants that have leaves designed to catch and digest insects. These plants do not obtain energy from the insects they digest; they all contain chlorophyll and produce their own sugars. Most of them, however, live in soils which lack usable nitrogen. Insectivorous plants obtain nitrogen from digested insects. Some of these plants, if grown in soil with ample nitrogen, will not properly form their insect-catching traps.

❑ *Venus's-flytrap* Probably the most familiar insectivorous plant, the 10-15 cm (4-6 in.) Venus's-flytrap, is found in moist soils in the

Venus's-flytrap

coastal regions of North and South Carolina. The leaf blade is an effective insect-catching trap. The red color of the trap and the sweet fluids it secretes attract flies and other insects. When the insect disturbs a set of epidermal hairs near the midrib, the two sides of the leaf quickly shut and squeeze the victim. Inside the closed trap secreted enzymes digest the insect in a week to ten days. Then the blade reopens, ready to receive another victim. Usually the leaf dies after it has closed for the third time.

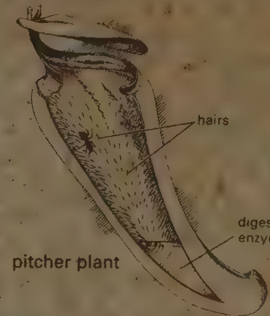
sundew with fly

❑ *Sundew* A small, ground-hugging insectivorous plant with red-tinged leaves is the sundew. Each leaf has about 100 tiny tentacles, each equipped with a drop of sticky, sweet, enzyme-containing material that attracts insects. When an insect touches a tentacle, the others converge on it. Enzymes digest trapped insects.

❑ *Butterwort* On the inside of the narrow, curled leaves of the butterwort are hairs which secrete a sweet, sticky substance that contains enzymes. When an insect touches these hairs, the leaf curls shut until the insect is digested.

Butterwort with ant

❑ *Pitcher plants* There are many different types of pitcher plants, some of which are tropical epiphytes. A pitcher plant produces hollow leaves which usually have a lip over the top to prevent excess rain water from entering the pitcher. In the bottom of the hollow leaf is a sweet fluid containing digestive enzymes. Most often there are hairs in the neck of the pitcher plant, all of which point downward. When an insect begins to move toward the sweet fluids it cannot return. In time it falls into the pool of enzymes.



pitcher plant

❑ *Bladderwort* A floating plant, the bladderwort has bladders which are insect traps. Each small pouch has several hairs near its opening which, when touched, snap shut over the opening, pushing the aquatic insect inside. Digestive enzymes are then secreted.

Review questions on page 322.

insectivorous: in- (in) + -secti- (L. SECARE, to cut) + -vorous (L. VORARE, to devour)

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents a survey of various insectivorous plants, how they capture insects, and what these plants obtain from the insects they digest.

The term **insectivorous plants** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

The Venus's-flytrap produces pink flowers and also reproduces by runners.

Many of the insectivorous plants spoken of in this Facet can be grown in pots or terrariums in the classroom. Various slides of these are available.

halophyte: halo- (Gk. HALS, salt) + -phyte (plant)

This box contains supplemental material which should be studied by most students. Omit this box if time is limited. There are no terms in this box which are listed at the end of the chapter.

Diffusion passes the dissolved materials to the vascular tissues of the plant.

Fertilizer "burn" is discussed on page 86.

Hydroponics involves growing plants in solutions of water and various minerals. Healthy plants can be grown in a water culture if air is bubbled around the roots. A few years ago it was hoped that culturing plants in water could be used in greenhouses to produce off-season fruits and vegetables, eliminating the need for large amounts of soil which must be constantly fertilized and replaced.

One of the difficulties with hydroponics is supporting the plant. Rocks, screens, and various fibers have been tried. Hydroponics is not widely used for cultivating foods but is used in some plant experiments because the minerals a plant receives can be easily controlled.

Hydroponics has also been called chemical agriculture, tank farming, and soilless plant growth.

Healthy plants can be grown in air if the roots are repeatedly sprayed with a mineral-rich solution.

by stopping the supply of oxygen necessary to keep root cells alive. The absorption of minerals stops as the oxygen supply decreases.

If a plant is grown in a soil that has too many soluble materials (such as might happen when an area is overfertilized), there is a higher concentration of ions outside the cell. Now, rather than being moved by active transport, the ions enter in large concentrations, and water molecules leave the cytoplasm to go into the soil. This loss of water causes *plasmolysis* and death of the root epidermal cells. If this cellular destruction is extensive, it will cause the plant to wilt, turn brown, and die. Because of this appearance, plants that have been damaged by overfertilization are said to be "burned" by the fertilizer.

Some soils having high concentrations of salt, even higher than seawater, can still support plants. Plants that grow in these conditions are called *halophytes** (HAL uh FYTES). They have higher concentrations of salts inside their cells than in the soil around them. Salt crystals often form on halophyte leaves as water evaporates from them.

Organic Gardening

Some people feel that *organic gardening,* the adding of mulch only, produces plants which are more beneficial as food than plants which are grown with chemical fertilizers. When deciding which method is best for a particular situation, a grower must consider many factors. One aspect that is *not* important is the source of the substances themselves (minerals and so forth). Plants cannot distinguish between a nitrate from a chemical factory and a nitrate from decomposing leaves because there is no chemical difference between them. The quality of the individual nutrient is not affected by the source from which it comes.

Other factors such as the soil texture, the availability of minor nutrients found in mulch but not often added to chemical fertilizers, *could* make a difference in the decision to use chemical fertilizers or organic matter. Plants grown only using organic mulches and organic fertilizers are not of a better quality than those grown using a good blending of organic gardening and nonorganic fertilizers.

Review Questions 13A-2

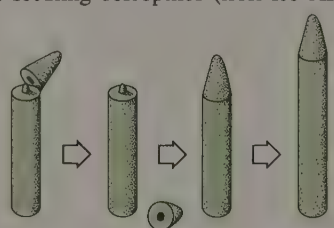
1. List three ways of replenishing the mineral content of the soil.
2. Explain how plants absorb minerals from the soil.

Facet 13A-1: Plants That Catch Insects, page 321

What value does catching insects have for insectivorous plants?

Plant Hormones

In the mid-1920s Fritz W. Went, a Dutch plant physiologist, performed a series of experiments on oat seedling coleoptiles (KOH lee AHP tilz).



13A-3 *Went's first coleoptile experiment*

When the coleoptile tip which contained the apical meristem was removed, cell elongation stopped. When Went replaced the coleoptile, elongation continued.

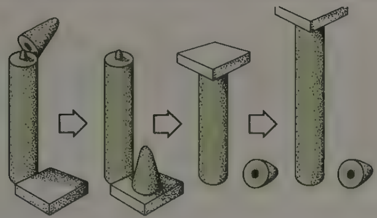
If the coleoptile tip was placed on a thin piece of agar and left for a time, the agar, if placed on the coleoptile, would cause elongation to resume. If a piece of untreated agar was put on the seedling tip, no elongation occurred. The untreated agar showed that the elongation was not caused by the weight of the tip but by a substance produced by the coleoptile tip that entered the agar and then passed to the seedling.

Answers–Review Questions 13A-2

1. (1) Crop rotation; (2) addition of fertilizer; (3) addition of mulch (decomposing organic material)
2. Usually minerals are absorbed into the roots in soluble form through active transport. This process depends upon the amount of oxygen available to the plant's root cells.

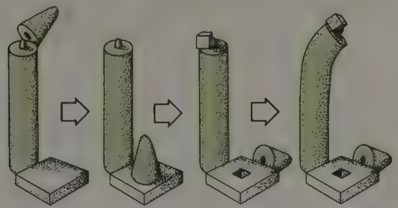
Answer–Facet 13A-1

Insectivorous plants must obtain nitrogen from digested insects since the soil they live in usually lacks nitrogen.



13A-4 *Went's second coleoptile experiment*

In another experiment a section of treated agar was put on only one side of the seedling. Elongation happened on that side only, causing the coleoptile to bend toward the opposite side. The chemical which Dr. Went presumed to cause elongation was later isolated and named *auxin* (AHK sin).



13A-5 *Coleoptile experiment in which the hormone is only placed on one side of the stem*

Auxins

Several auxins have been isolated from plant tissues. Auxins, along with several other plant substances, are called **hormones.** Plant hormones are chemical growth regulators produced in minute amounts by the meristematic regions and usually only affect nearby undifferentiated cells.

Auxins* are commonly found in stems, seeds, leaves, fruits, and in smaller quantities in roots. Auxins move from the top of the shoot toward the base. This movement, however, is not caused by gravity but by an unexplained force. Auxins vary greatly in their effects on different plants and on different areas of the same plants.

The elongation of the coleoptile tips observed by Went was caused by the most common auxin *indoleacetic acid* (IAA). IAA is necessary for the elongation of cells in the maturation region of stems. The rate and amount of elongation varies with the amount of the hormone. If the quantity of IAA in a leaf or a fruit drops below a certain level, the abscission layer at the base of the petiole forms cork cells, and the fruit or leaf will drop off. Fruit growers spray IAA on their orchards to keep the ripe fruit on the trees so that all the fruits can be harvested at one time.

Auxins can force unfertilized flowers to develop into seedless fruits. Auxins are used commercially to stimulate the formation of roots in woody stem cuttings. Auxins produced by terminal buds serve as inhibitors to lateral buds. Potatoes are sometimes sprayed with auxins to inhibit sprouting of the eyes (lateral buds). The synthetic auxin 2,4-D, when applied in lower concentrations, kills broad-leafed plants like dicots but does not affect narrow-leafed plants like grasses. 2,4-D is used as a lawn weed killer.

Gibberellins and abscissic acid

At the same time Went was doing his work, Japanese scientists were studying "foolish seedling disease" in rice. The rice plants grew very quickly but were too spindly to stand. It was discovered that *Gibberella fujikuroi,* a fungus associated with the rice seeds, produced a chemical that, when isolated, caused sprouts to grow rapidly. The chemical was named **gibberellin** (JIB uh REL ihn). At first it was thought that this chemical was foreign to plants, but over twenty different gibberellins have since been isolated from plant tissues.

Gibberellins stimulate both cell division and cell elongation in leaves and stems. When these

13A-6 *The plants on the right were given growth hormones. The plants on the left are growing normally.*

auxin: (Gk. AUXEIN, to grow)

Do not have students memorize Went's name and date, but rather the significance of his experiment.

Visual 13A-2 can be used to present Dr. Went's coleoptile experiments. Consider using discovery teaching (inquiry) to introduce plant hormones.

Through hormone action, undifferentiated cells are changed from independent units into correlated parts of a unified system.

A small amount of IAA is necessary for root elongation. A large amount, however, retards growth.

Auxins also influence the formation of vascular tissues by the vascular cambium. A possible classroom demonstration: In identical soils and pots, plant stem cuttings that have been exposed to rooting hormone (available at garden centers [follow directions]) and others that have not. Keep moist. After a few days uproot and compare root growth.

See leaf abscission (p. 304).

tropism: (Gk. TROPOS, turn)

phototropism: photo- (light) + -tropism (turn)

geotropism: geo- (Gk. GE, earth) + -tropism (turn)

thigmotropism: thigmo- (Gk. THIGMA, touch) + -tropism (turn)

chemotropism: chemo- (chemicals) + -tropism (turn)

hydrotropism: hydro- (water) + -tropism (turn)

Some scientists feel that *cytokinins (kinins)* should not be classified as plant hormones since they affect the tissues in which they are produced and are not translocated to other areas. Cytokinins affect plant cell division. In association with auxins, cytokinins cause plant tissue to divide rapidly, giving rise to many small cells.

Scientists have conducted interesting experiments in which plants were grown in artificial gravity (such as centrifugal force) and in the weightlessness of space.

plant hormones are applied to dwarfed plants, the plants will grow to their usual height. It could be that, through a mutation, the plant lost the ability to form gibberellins and responds as if the applied hormone were its own. Gibberellins are involved with flower, pollen and fruit formation in some plants and stimulate growth of some seeds.

Abscissic acid appears to stimulate the falling of leaves and fruits. Abscissic acid causes growing leaves to yellow and cork layers at the base of the petiole to begin forming. When applied to growing tips, it forces the formation of dormant buds. According to some scientists, abscissic acid is not a hormone but is an inhibitor to plant growth hormones.

Tropisms: plant growth responses

The growth of a coleoptile with an auxin on only one side is similar to the growth of plants in response to various environmental stimuli. For example, we are familiar with plant stems and leaves growing toward the light. Varying auxin concentrations account for this response. Light appears to cause auxins to migrate to the other side of the stem. The side with the highest concentrations of auxins elongates the most, causing the stem to grow away from the dark, hormone-containing side and toward the lighted, hormone-destroying side. A growth response in plants caused by hormonal action is called a **tropism.***

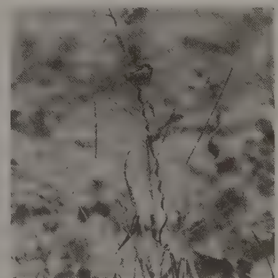
There are several types of tropisms, named according to the environmental condition which causes them.

❑ **Phototropism,*** a growth response to light, is not the same in all plants or plant parts. Plant stems respond with growth toward the light, called *positive phototropism.* Auxins, however, inhibit root growth. Since roots grow away from the light, they exhibit *negative phototropism.*

❑ **Geotropism*** is a response to gravity. Normally roots have *positive geotropism* while stems have *negative geotropism.* Gravity seems to affect the root, causing more auxins to be on the lower side. This inhibits growth on this side, causing the root to grow downward.

13A-8 *Geotropism of a corn seedling in three different directions. The stem is negative, the root positive.*

❑ **Thigmotropism*** is the response to touch. The elongation of a stem on the side opposite to the side touched is *positive thigmotropism.* The tendrils of grapes and peas, as well as the stems of some vines like the morning glory, exhibit *positive thigmotropism.*



13A-9 *The stems of the morning glory have positive thigmotropism, causing them to twine around whatever they touch.*

13A-7 *The stem of the bean seedling (right) shows positive phototropism, the root shows negative. The leaves of the African violet (left) have begun to grow toward the light.*

❑ **Chemotropism,*** the growth response toward or away from certain chemicals, is in many cases similar to hydrotropism.

*Hydrotropism,** the growth of roots toward water, was once held as an explanation for the full growth of tree roots in water-rich soil while drier areas around the tree remain rootless. There is, however, a much simpler explanation for this

Answers–Review Questions 13A-3

1. This experiment demonstrated the presence of a certain substance produced in the coleoptile that caused elongation. This chemical substance (a hormone) was later isolated and named auxin.

2. (1) Auxins, such as indoleacetic acid, cause elongation of cells in the maturation region. Auxins can also cause unfertilized flowers to develop into seedless fruits. (2) Gibberellins stimulate cell division and elongation in leaves and stems. (3) Cytokinins (kinins) cause rapid cell division. (4) Abscisic acid stimulates falling of leaves and

growth. When plant roots enter watered areas, they grow in abundance, while roots in less favorable conditions do not grow as well.

In experimental conditions plant roots have all grown at the same rate until some roots reached an area of abundant water. The watered roots grew faster, and the other roots continued in the direction they were growing rather than turning toward the water. Plants cannot sense where water is or grow toward it. Evidences of hydrotropism are usually only evidences of good and bad growing conditions and not really a tropism at all.

Review Questions 13A-3

1. Describe and tell the significance of Went's coleoptile experiment.
2. List four plant hormones. In what ways do these hormones affect plants?
3. How do tropisms affect plants? List several examples of positive and negative tropisms.
4. Explain why many researchers feel there is no hydrotropism in plants.

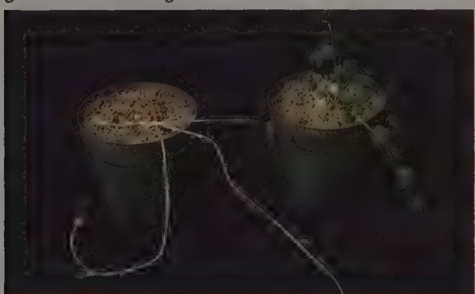
Plants and Light

Although all plants require light for photosynthesis and other processes, some need more light than others. Plant catalogs often indicate which plants grow best in shady areas and which require full sun. Sun-loving zinnias will be small and produce pale flowers if planted in the shade, and shade-loving impatiens will be scorched if planted in a sunny spot. As most window gardeners know, even the direction of light affects plants. Phototropism will cause geranium leaves to hug the glass if the pot is not faithfully rotated. Until the early 1900s, however, most people were not aware that even the length of time light is available to a plant is important.

Intensity of light

A plant that does not receive adequate light becomes **etiolated** (EE tee uh LATE ed): stem growth is rapid, but both size and number of leaves are greatly reduced. The plant appears to be stretching for light. Since light is necessary for chlorophyll production, etiolated plants are pale green, yellow, or even white. The stem elongates abnormally because auxins are not being destroyed by light.

13A-10 *The pea plants on the left were grown in darkness and are etiolated. The plants on the right were grown in normal light.*



Some plants, like the dogwood, have two growth patterns, one for full sun and another for shade. Most trees produce different types of leaves in the shade and in the sun, with differing amounts of palisade mesophyll, air spaces, stomata, and chlorophyll to accommodate the different conditions. In some trees, like the maple, *sun leaves* and *shade leaves* can be produced on various parts of the same plant, but the difference between the two types may only be found by careful observation.

Photoperiodism—the length of light periods

A variety of tobacco called Maryland Mammoth grows to be 3-5 m (10-16 ft.) high and produces many leaves, but when grown in Maryland, it does not begin to flower until cold weather sets in. The plants are killed by frost before the seeds form.

In 1906 research was begun to find out why this tobacco flowers so late. If seeds were planted in Maryland greenhouses in the late summer, the plants would flower at the same time as those planted outside, even though they were not nearly as tall as their outdoor counterparts. After more than fifteen years of research, studies were published describing how the length of day and night affects the flowering of many plants, a phenomenon now called **photoperiodism.***

photoperiodism: photo- (light) + -periodism (Gk. PERIODOS, circuit)

Light intensity is one of the major factors in success with house plants. A house plant may either become etiolated if it does not get enough light or turn brown if it gets too much light. A plant may either not grow or not flower if it is not getting the right light intensity.

All short-day and long-day plants flower best in certain narrow ranges of photoperiods. This ideal illumination period for each species is known as the *critical day length.*

Short-day plants produce flowers at their critical day length or at photoperiods that are shorter than their critical day length. For example, poinsettia plants produce flowers when the photoperiod is 12-12 $\frac{1}{2}$ hours (their critical day length), but they will also flower at shorter photoperiods. If the photoperiod continues to decrease, however, the number, size, and general quality of flowers will decrease, and there may be insufficient illumination to maintain adequate photosynthesis for growth. Poinsettia growers often expose the plants to the critical day length just long enough to have the plant form flower buds and then give it long days so that it will produce large, abundant flowering even on small plants. The difficulty of doing this explains the "poor show" of homegrown poinsettias.

Long-day plants produce flowers at their critical day length or at longer photoperiods. For example, spinach flowers best at photoperiods of 13-14 hours but will flower during longer photoperiods.

Thus, short-day plants generally flower in early spring or in late summer and fall; long-day plants, during late spring and summer.

fruits. It may be an inhibitor to plant growth hormones.

3. Tropisms result in various growth responses to hormonal action, affected by light, gravity, touch, and chemical stimuli. Positive tropisms include phototropism of stems (toward light), geotropism in roots (downward growth), thigmotropism (elongation of the stem on side opposite to side touched), and chemotropism (growth toward chemical stimuli). Negative tropisms include phototropism (growth of roots away from light), geotropism (upward growth, as in stems), and chemotropism (growth away from chemical stimuli).
4. Evidences of hydrotropism are really supposed evidences of good and bad growing conditions. In experiments plant roots have not been observed to grow *toward* water but do grow rapidly when they reach water. Such growth is not a tropism.

This Facet contains supplemental material which should be studied by most students. Omit this Facet if time is limited. This Facet presents the concept of dormancy in plants: how it benefits the plants and how dormancy is broken.

The term **dormancy** is listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know this term for testing purposes.

In 1879, seeds of 20 species of weeds were stored under conditions designed to keep them dormant for 160 years. In 1970, the seeds of only 3 species were still viable.

Many seeds growing in areas with marked seasonal temperature variations require a period of cold to break dormancy and induce germination.

Seeds of some plants require soaking before planting in a garden in order to break dormancy.

Seeds found within the moist fruit of many plants must dry before they germinate, which keeps them from germinating inside the fruit.

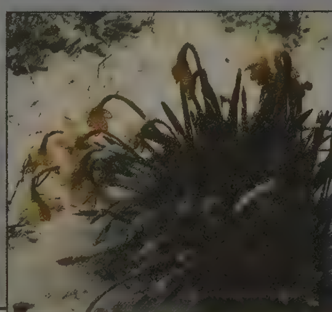
The cone shape of most evergreens helps to distribute the weight of snow and ice on a tree.

13A-2 FACETS OF BIOLOGY

Dormancy in Plants

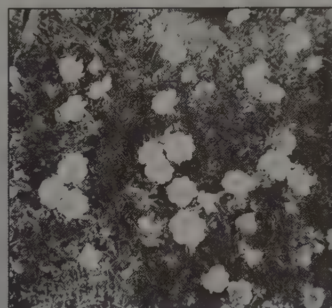
Most plants encounter conditions unfavorable for growth at some time during the year. Annuals die during this period, leaving seeds to continue the species. Some herbaceous plants leave roots which sprout the following year. Some woody plants lose their foliage and form dormant buds, which sprout when favorable conditions return. Where the conditions do not get too severe, some plants merely stop growth and wait for better times. For all these plants the period of inactivity is called **dormancy.** Plants have been keyed by the Creator to have their dormant periods terminated by precise conditions so that unusual quirks in the season do not cause early breaking of dormancy, thus destroying the plant.

After a tulip blooms in early spring, it forms a floral bud and by all outward signs is ready to sprout again by mid-summer. The summer sun, however, would scorch and kill the leaves of the plant. The tulip is keyed to enter a period of dormancy after the bud is formed. A period of near freezing temperatures, which destroy certain chemicals in the bulb, breaks this dormancy. These chemicals prevent the tulip from sprouting in the summer or fall.



Daffodills are able to withstand cold. A late snow will not harm them, but 90° weather will kill them.

Some seeds have chemicals which inhibit sprouting. Only when these chemicals are washed away will the seed sprout. This is important for plants that need a rainy season in order to grow. On the other hand, maple tree seeds sprout as soon as they fall from the tree in early spring. It is essential that the maple seedling grow for a full season before winter comes; therefore, maple seeds will sprout even on a block of ice.



The rockrose is found in Israel. It grows and flowers during a brief rainy season and then becomes dormant. Some believe that this is the lily of the field spoken of in Matthew 6:28.

Corn seeds and other seeds which are formed in the fall require about 13° C (55° F) to sprout. If a corn seed sprouted as soon as it formed, winter weather would kill the young plant. A period of dryness and the spring temperatures are necessary to break the dormancy of corn seeds.

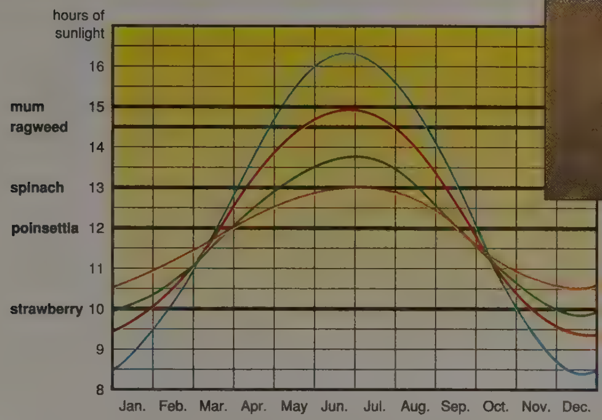
Some areas have two growing seasons in a year. These areas usually have dry, hot summers which force plants to grow only in the spring and fall. Some plants are designed to conquer this problem by rapidly growing and producing seeds in the few months of spring or fall alone. Some plants in these areas have leaves which can become dry, often curling up and becoming brittle; but when moisture returns, the leaves fill with water, and growth resumes. Without these God-designed mechanisms, the plants in these areas would have been killed long ago.

Some plants form seeds in order for their kind to survive unfavorable conditions.

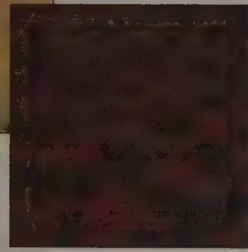
Review questions on page 328.

Answers–Review Questions 13A-4 *(p. 328)*

1. **(1)** Intensity; **(2)** length of daylight (photoperiodism)
2. Short-day plants are plants that flower when exposed to less than 12 hours of sunlight. They sometimes require less than 10 hours (e.g., chrysanthemums, corn, strawberries). Long-day plants require more than 12 hours of light (e.g., sunflowers, sweet clover, beets). Neutral-day plants (e.g., hybrid roses, beans, zinnias) flower independently of a photoperiod; usually they flower continuously if other conditions (e.g., temperature, moisture) are favorable.



ragweed



poinsettias

13A-11 *The length of the daylight period at different times of the year for several U.S. cities has been plotted on this graph. The length of the photoperiod for several plants is indicated on the left. Strawberries (short day plants) are stimulated to flower by 10 hour days and thus bloom in the spring. Spinach blooms only when the photoperiod is about 13 hours (long-day plant). Although mums require a long day to flower, the formation of buds and flowers takes time, and they bloom in the early fall in most areas where they grow outdoors. Since they bloom in the fall, some botantists consider them short-day plants.*

phytochrome: phyto- (plant) + -chrome (color)

Explain that the ragweed flowers in response to the decrease in photoperiod length from more than $14\frac{1}{2}$ hours to $14\frac{1}{2}$ hours. Since the southern Florida photoperiod never exceeds that length of time, it, of course, cannot decrease to it, which is the condition for flowering.

The length of daylight varies greatly, depending on the season as well as the latitude. Knowledge of its photoperiod enables scientists to predict when a plant will flower.

Most plants grown in temperate areas are divided into three groups:

- *Short-day plants* flower when the period of light is less than 12 hr.; sometimes less than 10 hr. is required for flowering. Some examples are poinsettias, goldenrods, asters, soybeans, corn, and strawberries.
- *Long-day plants* flower when the period of light is more than 12 hr. Some examples are sunflowers, hollyhocks, sweet clover, irises, and radishes.
- *Neutral-day plants* flower independently of the photoperiod. These plants usually flower continuously if temperature, moisture, and various other conditions are favorable. Hybrid roses, beans, tomatoes, carnations, snapdragons, peas, marigolds, and zinnias are common neutral-day plants.

As soon as many plants mature, they produce flowers if the photoperiod is right. Some plants will not flower if a photoperiod is off 10 min.

The physiological processes of photoperiodism are based on plant pigments called *phytochromes** (FYE tuh KROHMZ). Two forms of the phytochrome responsible for photoperiodism are found in plants. Light changes one form to the other, and darkness changes it back. Plants flower when the ratio of these two phytochromes is right for that particular variety. In many plants a single exposure to the proper photoperiod induces flowering. In most plants the period of darkness appears to be the critical factor. If the dark period is broken even by a short exposure to dim light, many plants will not flower.

In combination with the photoperiod, plants often flower in response to temperature, available moisture, and other factors. Many spring-flowering woody plants such as fruit trees, azaleas, and dogwoods, along with many flowering bulbs like tulips, crocuses, and hyacinths, form their flower buds one year (often in response to photoperiod changes and to decreased temperatures) and flower the next year following a dormant period, regardless of the photoperiod.

Biological Terms

Plants and Water	topsoil	root pressure	capillarity
soil texture	humus	passive absorption	transpiration
loam	pore spaces	translocation	cohesion

Answers–Facet 13A-2

1. By remaining dormant during certain parts of the year, the plant is not subjected to harsh conditions that would injure or kill it. Dormancy is a means of protection for plants.
2. Temperature (cold for some, hot for others), dryness, or moisture breaks dormancy in different plants.

Answers–Thought Questions

1. The term is misleading because plants do not ingest food as animals do.

*2. Many variables are involved in such a comparison of the techniques. If the organic gardening techniques provide the necessary minerals and other nutrients for ideal plant growth, then they may be practiced. Other techniques that rely on commercial fertilizers and insecticides are sometimes criticized because they may poison fruits and vegetables. This may be true if the incorrect insecticides are used or if the insecticides are used incorrectly. However, if proper fertilizers and insecticides are used according to directions, and used only when required, there should not be a health problem. Usually, the ideal method is to use organic techniques as much as possible, supplementing with fertilizers and insecticides only when necessary.

3. The major factor involved would probably be a reduction in light. Another factor may be a change in temperature. However, this probably would be insignificant because the temperature in the various rooms of a house would not differ greatly unless the back bedroom is unusually cold. Perhaps the photoperiod, or possibly just a needed period of dormancy, caused the change.

*From a box.

transpiration-cohesion theory	*Plants and Minerals*	auxins	phototropism	photoperiodism
guttation	fertilizers	gibberellin	thigmotropism	*Facets*
nastic movement	mulch	abscissic acid	chemotropism	insectivorous plants
turgor (adj., turgid)	*Plant Hormones*	tropism	*Plants and Light*	dormancy
	hormones	geotropism	etiolated	

Review Questions 13A-4

1. List several characteristics of light that are significant for plant growth.
2. Compare and contrast short-day plants, long-day plants, and neutral-day plants.

Facet 13A-2: Dormancy in Plants, page 326

1. Summarize how a period of dormancy may help certain plants.
2. List several conditions that break dormancy for different plants.

Thought Questions

1. Why is it improper to speak of "plant food"?
2. Some people believe that those fruits and vegetables produced using organic gardening techniques are more beneficial than food grown using other techniques. List arguments for and against this opinion.
3. The plant that thrived in the living-room window all summer slowly turned yellow and lost its leaves when Mom moved it to a window in the back bedroom. Mom said she had been giving it the same amount of water and "plant food." List as many factors as you can that could account for the change in the health of the plant.

13B–Plant Reproduction

Specially named varieties of plants (e.g., Red Delicious apples, Concord grapes, Alberta peaches, and Valencia oranges) are reproduced vegetatively to assure continuation of each variety's distinctive characteristics.

Related material is found on page 126.

Visual 13B-1 can be used as an outline to present the various types of plant reproduction discussed in this chapter.

One of the characteristics of the plant kingdom is the presence of multicellular sexual reproductive structures. **Sexual reproduction** of flowering plants (phylum Anthophyta) involves the formation of flowers and seeds, the germination of those seeds, and the growth to a mature plant. Although some plants complete this life cycle in the space of a few weeks, others often require many years.

Because there is genetic variation each time there is sexual reproduction, a plant with exactly the desired traits (such as large fruit, certain flower color, or disease resistance) may not be produced by sexual reproduction. For example, a high quality red rose may produce hundreds or thousands of inferior rose plants by sexual reproduction before it has a high quality offspring.

Vegetative reproduction is asexual; therefore, the offspring have the same genetic makeup as the parent plant. Although all plants are capable of sexual reproduction, many ornamental and food plants are reproduced vegetatively since their potential for the various characteristics of species is already known. Also, vegetative reproduction often produces a plant capable of maturing years sooner than a seedling. In other words, in plants such as fruit trees, berry bushes, and many ornamentals, sexual reproduction may be used to develop new varieties and asexual reproduction may be used to "fill the field" with a good variety. But if all plants were reproduced vegetatively, we would not have any new varieties of plants and plant products.

13B-1 Commercially Important Plants

Vegetatively reproduced
almond, apple, banana, blackberry, cherry, chrysanthemum, fig, grape, holly, iris, Irish potato, lily, olive, orange, orchid, peach, pear, pecan, pineapple, poinsettia, rose, strawberry, sweet potato, tulip

Sexually reproduced
barley, bean, broccoli, cabbage, carrot, celery, coconut, corn, cotton, cucumber, lettuce, maple, marigold, melons, oak, pea, peanut, pine, rice, soybean, tomato, turnip, wheat

13B–Plant Reproduction

Notes–Chapter 13B

The reproduction of flowering plants is the topic of this chapter. (Chapter 12A dealt with the reproduction of the other plant groups.) The teaching of this chapter can benefit from a number of classroom examples. Consider using a house plant that produces plantlets on its leaves and another on runners (the spider plant is a common one). Air layering can easily be done in a classroom. Make a collection of different flowers, or ask a local florist for specimens that are "not in good condition." From the grocery and a trip around the yard or woods, bring to class a collection of common and uncommon fruits to classify. Have various types of seeds (peanut, corn, sunflower,

Objectives–Chapter 13B

- ❑ Distinguish between natural and artificial methods of vegetative propagation. List and describe several examples of each method.
- *❑ Explain the concepts of grafting and budding and discuss their importance in modern agriculture.
- ❑ Draw, label, and give the functions of the structures in a complete flower.
- ❑ Describe pollination in a flower.
- ❑ Describe fertilization in a flower.
- ❑ Define *fruit*, giving names and examples of various types.
- ❑ Describe the structures of a typical seed. Give the functions of a seed.
- ❑ Discuss seed germination requirements and their significance.

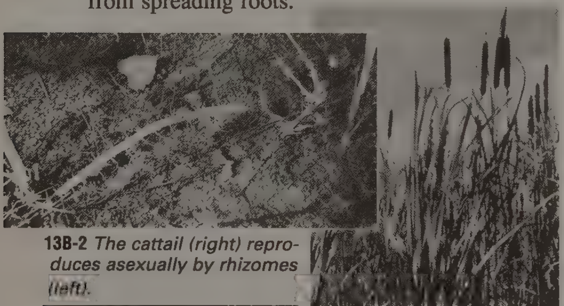
*From a Facet.

Vegetative Reproduction

Vegetative reproduction of plants can be *natural*, that is, carried on by the plant itself, or it may be *induced*. Induced methods of vegetative reproduction attempt to force the meristematic tissues to grow the missing parts of the plant. Similarly, natural methods of vegetative reproduction sometimes result because a portion of a plant forms the structures to make a complete plant. Often, however, on special stems or leaves the parent plant will form small complete plants called **plantlets** which can grow independently.

Vegetative reproduction by underground parts

If a single sprig of mint is planted in a garden, soon dozens of mint shoots will appear around the original plant. Underground *stolons* like those found in the mint are often responsible for vegetative reproduction. The common cattail, if started from the seed, can in a single year produce almost one hundred shoots from its spreading *rhizomes*. The seeds establish cattail rhizomes in new areas, but vegetative reproduction produces new plants around the parent. Plants like iris, bamboo, lilac, elderberry, grass, and many herbaceous weeds reproduce by rhizomes, stolons, or shoots produced from spreading roots.



13B-2 *The cattail (right) reproduces asexually by rhizomes (left).*

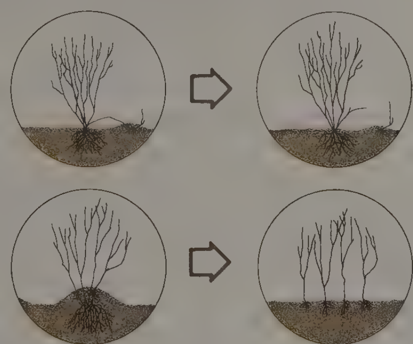
Corms and bulbs are underground stems that can reproduce vegetatively. Once a corm or bulb matures, tiny corms or bulblets develop from lateral buds at the base of the parent plant. Tulips, hyacinths, and daffodils reproduce this way.

Commercial bananas produce a corm which is sometimes over 30 cm (1 ft.) in diameter. This corm is cut into pieces weighing 1.5 kg (3.3 lb.). Each piece must have a bud on it. If the piece is planted, a new shoot will appear and grow to 9 m (29 ft.) tall, 40 cm (16 in.) in diameter, and produce fruit in 12-16 months. The shoot is herbaceous and will produce fruit only once. The aboveground portions of the plant are cut away after the fruit is harvested. The new corm will then send up more shoots from lateral buds, or it may be dug up, cut, and replanted.

Tubers are underground stems which, unlike most corms and bulbs, often produce abundant lateral buds, each of which may develop into a new plant. The white or Irish potato can be propagated by cutting apart the tuber and planting its "eyes" (lateral buds).

Vegetative reproduction by stems

Runners are usually spindly stems which produce plantlets at their tips. When the plantlets grow too heavy to be supported, the runner bends to the soil where the adventitious roots set in, and a new plant develops. Once the plantlet roots begin to grow, the runner dies. Runners, a common method of natural asexual reproduction, are seen in strawberry plants, spider plants, and eelgrass.



13B-3 *Simple layering (top) and mound layering (bottom) are two methods of layering commonly used to propigate plants asexually.*

Stems are often used in induced vegetative reproduction. A common practice among nurserymen is **layering.** In layering, the stem of a parent plant is usually bent over and buried in moist soil. Often the stem is wounded to reveal meristem and then treated with rooting hormones. In time most plants produce roots from nodes or at the

Review rhizomes, stolons, etc. (pp. 308-9).

Simple layering is the method described in the text. The rose, honeysuckle, blackberry, raspberry, and rhododendron reproduce in this way.

peas, beans, wheat, rice) that students can cut open and examine at their desks.

Keep the material flowing rapidly. Slowing down with this simple material will produce boredom.

The Facet dealing with grafting and budding contains interesting information that should take only a few minutes in class.

It is often wise to cut away most of the growing tips of the aerial portion of a stem cutting. Why would this be advisable? The growing tips of the anterior portion of a stem use much of the available water and nutrients. Cutting them away is advisable because the water and nutrients can then be used entirely to grow roots. Frequently, root-including hormones are used to hasten this process and to increase the rate of success.

wound. This rooted stem is then cut from the parent plant and replanted. Raspberry and blackberry plants produce spindly stems which often fall over and layer themselves naturally.

A **stem cutting,** or *slip,* is usually a section of a woody stem that is placed in water or in moist sand, soil, or a similar medium. Exposing the meristematic tissues in lateral buds or nodes to moist conditions promotes the growth of roots. Different plants have various requirements for rooting in this manner. Placing some cuttings in water will result in rotting rather than rooting. Many cuttings are best started as the plant enters or is in dormancy; others are best started when the plant is supporting mature foliage. Several plants commonly reproduced by cuttings are hollies, yews, pineapples, cacti, camellias, and roses.

The stems of many vines reproduce asexually. Vine nodes often have adventitious roots for climbing. If these roots contact the soil, they can begin to grow and thereby produce new plants.

13B-4 *Kudzu, a Japanese import, is grown in the U.S. to prevent soil erosion and may grow 50 ft. in a summer. The stems become woody and produce roots at nodes. The roots grow, produce buds, and become new plants. Kudzu has escaped cultivation, and threatens native plants.*

Under proper conditions almost any leaf can be forced into vegetative propagation. Most leaves, however, wilt and die long before their tissues develop new plants. A couple of notable exceptions are members of the African violet family and succulent-leafed tropical and semitropical plants (often seen as houseplants). A leaf rooting in water or moist soil is called a **leaf cutting.**

Review Questions 13B-1

1. Why are some plants commercially reproduced asexually? What is the value of sexual reproduction of commercial plants which are usually asexually reproduced?
2. Differentiate between natural and induced methods of vegetative reproduction.
3. List several plants that are asexually reproduced by underground roots or stems.
4. Describe the process of layering.

Sexual Reproduction

Students should be able to identify the pedicel, receptacle, sepals (calyx), petals (corolla), pistil, and stamens (filaments and anthers) in most typical flowers. Observation of samples or photographs of different plants should help.

In the plant kingdom sexual reproduction is carried on in a variety of ways. Sexual reproduction in the phylum Bryophyta differs greatly from the ferns and the gymnosperms. The anthophytes (angiosperms, phylum Anthophyta), which will be discussed in this section, have a basic similarity in their sexual reproductive processes but almost limitless variety in the structure of their flowers, fruits, and seeds. The goal of sexual reproduction, no matter how it is accomplished, is to produce new plants and to recombine genes into different groupings, thereby occasionally producing other varieties.

The flower

Although flowers vary greatly, there are only six basic floral parts. The lower and outermost structures (pedicel, receptacle, sepals and petals) are *accessory flower parts.* The inner two (the anther and pistil) are the *reproductive parts of a flower.* Usually each flower has only one each of the first two flower parts.

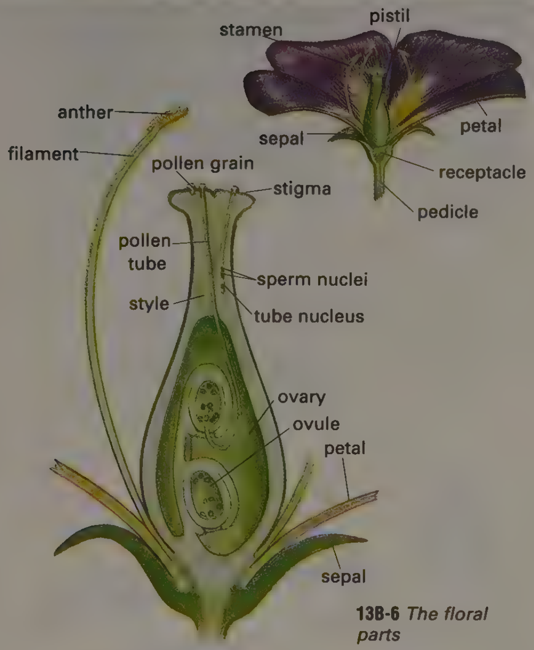
- **Pedicel** The pedicel is the stalk which supports the flower.
- **Receptacle** The enlarged end of the pedicel which bears the remainder of the flower parts is the receptacle.

The other four flower parts are arranged roughly in rings, and flowers often have multiples of each of them.

13B-5 *A tulip cut to show flower parts. Does the tulip have a superior or inferior ovary?*

Answers–Review Questions 13B-1

1. **(1)** Some plants are reproduced asexually by man to preserve their inherited characteristics in the new plants. There is no genetic variation by this method; thus, desirable qualities can be maintained. Also, asexual reproduction often produces a plant that is capable of maturing years sooner than a seedling. **(2)** Sexual reproduction is often used to develop new varieties of plants.
2. Natural vegetative reproduction is carried on by the plant itself. In induced vegetative reproduction, meristematic tissues are stimulated to grow missing parts of plants.
3. Underground roots–iris, bamboo, lilac, elderberry, grass; underground stems–tulips, hyacinths, daffodils, banana plants, potatoes (tubers)
4. In layering, a plant's stem is usually wounded, and the exposed meristematic tissues are exposed to wet conditions so that they develop roots. Once roots develop, the stem can be removed from the original plant and planted. There are many forms of layering. Simple and mound layering are presented in the text.



13B-6 *The floral parts*

❑ **Sepals** The outermost ring is composed of the sepals,* collectively called the *calyx** (KAY liks). Sepals are often green and serve to protect the other floral parts as they form in the bud. As in the tulip, however, sepals may be colored and even be indistinguishable from the petal.

❑ **Petals** Petals, often large and brightly colored, are just inside the sepals. Together the petals are called the *corolla** (kuh ROHL uh).

❑ **Stamen** The male reproductive structures, the stamens, comprise the next ring. The stamen is made of the **filament,** or the stalk which bears the **anther.** An anther has four chambers in which **pollen grains** are formed. Pollen grains vary greatly in size and surface structures and contain the male gametes of the plant.

❑ **Pistil** The female reproductive structure, the pistil, is the innermost floral part. The pistil is made of the **stigma,** which when mature has a sticky surface to receive the pollen; the **style,** which supports the stigma; and the **ovary,*** which contains the ovules. If the *ovum* (egg) in the ovule is fertilized, the **ovule** develops into a seed.

Plant ovaries may contain a single ovule, as in peaches or pecans, or they may contain many ovules, like beans, apples, or tomatoes. Some flowers have multiple pistils. The strawberry and magnolia have many individual pistils on a single receptacle. Ovaries of flowers may be *superior,* above the receptacle, or *inferior,* within the receptacle. Occasionally a *floral tube* (fused petals or fused petals and sepals) may cause a superior ovary to appear inferior.

If a flower has sepals, petals, and at least one stamen and one pistil, it is called a *complete flower.* Flowers which lack any of these structures are *incomplete flowers.*

Pollinations

Many complete flowers have showy petals that aid in the transfer of pollen by insects or birds. *Nectar,* a sweet fluid secreted at the base of the petals, is the lure which brings these animals to the flowers. The corolla is often designed as a sort of bull's-eye to guide the pollinators to the nectar.

The anthers and the stigma are usually held in a position so that anything reaching the nectar will have to pass them, thereby aiding pollination. Although some flowers, like the members of the pea family, have their petals wrapped around the stamen and pistil, insuring *self-pollination,* most flowers have mechanisms aiding the probability of *cross-pollination.* Often the stamen and the pistil mature at different times. Some pistils are arranged so that an insect entering the flower will place pollen on the stigma, but as it leaves with pollen from the stamen of this flower, it will not pass the sticky part of the stigma. Some species will not produce seeds if their pistil receives pollen from a stamen of the same flower, or in some cases, from the same plant.

Many flowers, usually incomplete ones, are pollinated by wind. They have no need of showy petals and most often do not have them. Some plants produce male flowers, containing the stamen, and female flowers, containing the pistil. Squash and cucumbers develop from female flowers that contain the pistil. Squash and cucumbers are insect-pollinated plants with separate male and female flowers on the same plant. Many trees,

sepal: (Gk. SKEPE, covering)

calyx: (Gk. KALUX, cup)

corolla: (L. CORONA, crown)

ovary: ova- or ovi- (egg)

Visual 13B-2 can be used as an outline to teach parts and kinds of flowers.

Honey is made from nectar (see also pp. 380-82).

Self-pollination is the pollination of a stigma by pollen from the same flower or another flower of the same plant. Some self-pollinating plants are wheat, rice, peas, peanuts, flax, cotton, and tomatoes. Cross-pollination is the transfer of pollen from the flower of one plant to the flower of another plant of the same or similar species.

Insect pollination is of economic importance. Without certain insects, many plants will not produce seeds or fruits.

A carpal is a modified leaf which forms a pistil or part of a pistil of a flower.

The position of the ovary is significant in plant classification and in study of the nature of fruits.

integument: in- (in) + -tegument (L. TEGERE, to cover)

micropyle: micro- (small) + -pyle (Gk. PULE, gate)

endosperm: endo- (within) + -sperm (seed)

The pollen from wind-pollinated plants can cause hay fever.

This box on fertilization may be skimmed, simplified, or omitted if time is limited.

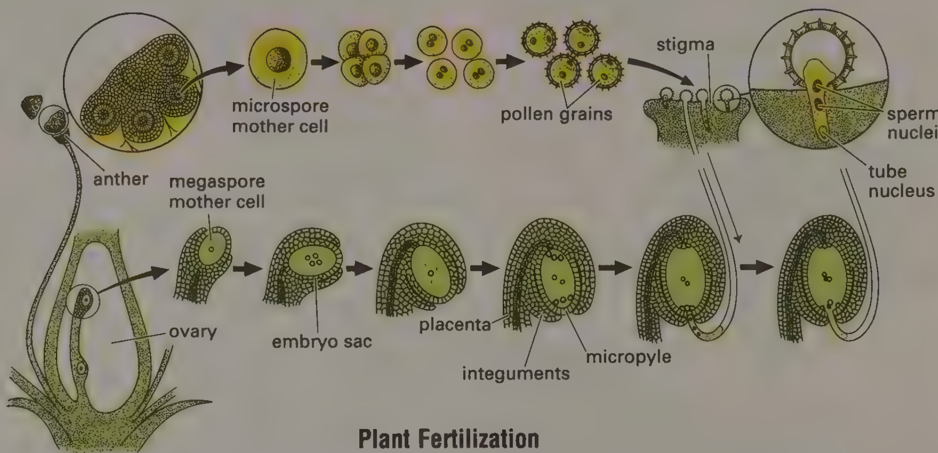
This box contains supplemental material which should be covered by advanced classes or classes involved in a detailed study of the plant kingdom. If the students' science background has been good, they should already know the basic flower parts. The material in this box is the next logical step in their botanical education. The material is not difficult, but it does take time. Omit this box if time is limited. The content of this box, however, does have a tendency to appear on standardized tests.

The terms **micropyle** and **endosperm** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

Double fertilization occurs only in the angiosperms.

like the oak and pecan, produce *catkins*, which are collections of stamens. Catkin pollen is carried by the wind to inconspicuous female flowers on other parts of the plant. Plants such as spinach, date palms, willows, holly, ashes, and some maples produce male flowers on one plant and female flowers on another.

13B-7 *The oak catkin (a male flower) lacks petals but produces abundant pollen for wind pollination.*



Plant Fertilization

Formation of Gametes

In a young anther chamber are large *microspore mother cells* which carry on meiosis to become *microspores*. Each microspore cell (which is haploid) goes through mitosis but does not divide its cytoplasm. One of the haploid nuclei becomes the *tube nucleus*. The other nucleus is the *generative nucleus*. Later the generative nucleus will divide by mitosis becoming 2 *sperm nuclei*.

Ovules begin as a swelling along the ovary wall, in which a large *megaspore mother cell* goes through meiosis. The *embryo sac* forms around the 4 cells produced by this division. Three of these haploid cells die; the *megaspore* is the cell that remains. Its nucleus divides by mitosis 3 times, resulting in 8 identical haploid nuclei. During this time the embryo sac has been growing and has become covered by *integuments** (in TEHG yoo munts). The integuments attach the ovule to the ovary wall by a stalk called the *placenta*. The **micropyle*** is a small gap between the integuments.

The Union of the Gametes

When a pollen grain lands on the stigma of the right species, chemicals manufactured by the stigma stimulate the growth of the pollen tube. The tube nucleus is near the growing tip of the pollen tube. Immediately behind the tube nucleus are the 2 sperm nuclei. The pollen tube grows down the soft tissues of the style, enters the ovary, and then enters the ovule through the *micropyle*. The tube nucleus then disintegrates.

One sperm nucleus fuses with the *egg cell*, which is 1 of the 8 haploid nuclei in the ovule. Five of the haploid nuclei in the ovule disintegrate. The other 2, found in the center of the ovule, fuse together and then fuse with the second sperm nucleus, forming a triploid nucleus. This triploid nucleus forms the **endosperm,*** which is stored food for the embryonic plant to use while in the seed and when sprouting. Because seed formation requires the fertilization of 2 nuclei inside the embryo sac by 2 sperm nuclei, it is *double fertilization*.

13B-1 FACETS OF BIOLOGY

Grafting and Budding

Although not technically a form of vegetative reproduction because no *new* plant is produced, *grafting* and *budding* are used to obtain the large number of genetically identical plants needed for commercial purposes. Many woody plants such as apples, peaches, and roses are reproduced this way.

Grafting is the process wherein a stem, called the **scion** (SYE uhn), is cut off from one plant and placed in contact with the stem of a rooted plant, called the **stock.** Thus the scion begins to grow on

the stock. There are several ways in which a graft can be cut and joined to the stock; each type of plant, however, has a way that works best. The idea is to get the *vascular cambiums* as close together as possible. When these cambiums produce cells, the cells become an undifferentiated mass. After a time, this mass joins the xylem and phloem. When the necessary strengthening and covering tissues are also formed, the graft has "taken," and the scion will grow on the stock.

Budding is similar to grafting, but rather than using a stem, a bud with a sliver of bark is placed under a slit in the bark of the stock. The top of the stock is cut off, and the grafted bud continues apical growth.

Usually grafting and budding are done while the plants are in dormancy. If the plants were growing, the water demands of the leaves on the scion would not be met while the new cells at the graft were forming. The wounds of the plant must be supported and sealed, usually with elastic tape and a waxlike or plastic substance to prevent the stalk and scion from wiggling loose and drying out. Usually successful grafting or budding will involve members of the same genus or at least the same family. Most often grafting is done with woody plants, but it may be done in some herbaceous plants.

Since the meristematic tissues of the stem produce the fruits, and since there is no exchange of genes between the meristematic tissues of the roots and the stems of a graft, the stock usually does not affect the scion, and vice versa. Roots supply water and dissolved minerals. As long as there is an adequate supply of both, the grafted-in portion of the plant will grow and express its genes normally.

When a slow-growing stock is used, the grafted-in portion may not be able to grow as rapidly as it normally would. This can produce dwarf plants. For example, the roots of the slow-growing quince cannot supply enough water for the rapidly growing apple. An apple grafted into quince roots will produce small trees with normal-sized fruits.

Review questions on page 336.

This Starkrimson Delicious apple tree was grown from a seed. Seeds of this tree will not produce the same variety of apples, however. All other Starkrimson Delicious apple trees are the result of grafting.

Biblical Grafting

The practice of grafting is centuries old. The Apostle Paul was thoroughly familiar with the principle and procedures of grafting. In Romans 11 he compares Gentile Christians to a grafted wild olive tree branch on the stock of a cultivated olive tree, the house of Israel. The scion is warned not to boast that the original branches were pruned for its sake. The Jews were pruned for the Gentiles' sake, but they were also pruned because of their disbelief. God says that He will prune any rotten branches and will graft in old branches if they repent.

This Facet contains supplemental material which should be studied by most students. Omit this if time is limited. This Facet presents the concepts of grafting and budding plants and Scriptural references to them.

The terms **grafting, scion, stock,** and **budding** are listed in the Biological Terms section at the end of the chapter. Be sure to inform students if they are expected to know these terms for testing purposes.

The box in this Facet deals with a Biblical reference to grafting. Teachers may wish to develop a short devotional based on this reference.

Using special techniques, some monocots can be grafted.

radicle: (L. RADIX, root)

13B-8 *Each of the petals of the mum actually has male and female parts. Since they are all on a common receptacle, the mum is a composite flower.*

The sunflower has a large receptacle with hundreds of complete, individual flowers arranged on it. On the outside rim there are sterile flowers which produce large petals but lack most other floral parts. A flower composed of many small flowers is called a *composite flower.* Daisies, chrysanthemums, dandelions, and clover are other composite flowers.

Seeds

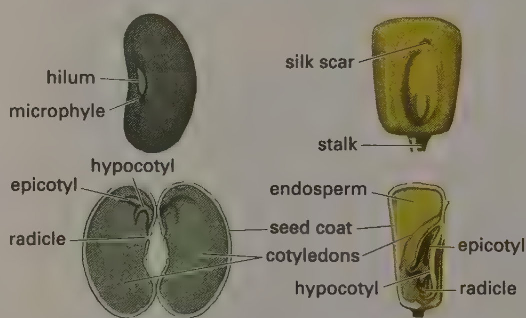
The agents of seed dispersal include wind, water, birds, insects, mammals, and man. Through commerce and travel, man has played an important role in the distribution of plants.

Seeds are made of a tiny embryonic plant, stored food, and a seed coat. The seed coat (sometimes called the *testa)* may be smooth and cover the content of the seed tightly, or it may be relatively loose-fitting. Some seeds, such as the milkweed, have fluffy extensions of the seed coat to aid the seed in dispersal. Most seeds reveal a **hilum,** which is the point where the seed was attached to the ovary wall, as well as a small scar indicating the **micropyle.**

If the cotyledons attach near the upper part of the hypocotyl, as in beans, they often are raised above the ground as the seed sprouts. If the cotyledons are attached close to the radicle, as in most plants, they remain below the ground.

The stored food contained in a mature seed may be in several forms. The bean, for example, has an *endosperm,* but it is used up by the embryonic plant as the bean forms. The stored food in a bean is found in its two **cotyledons.** Corn, on the other hand, has a single cotyledon and an endosperm within its seed coat. Remember that anthophytes are classified into two classes based on the number of cotyledons contained in the seed.

Tiny seeds often must germinate on the surface of the soil so that their leaves can be almost immediately exposed to the light. Their small quantities of stored food are quickly depleted; therefore, they must begin photosynthesis immediately after the seedling breaks out of the seed coat.



13B-9 *Structures of a bean (dicot, left) and a corn (monocot, right) seed*

The embryonic plant within the seed has three general areas, based on where the cotyledons attach to it. The part below where the cotyledons attach is the **hypocotyl** (HYE puh KAHT ul), the embryonic stem. The **radicle*** is the end of the hypocotyl which will develop into the primary root of the plant. The end above the point of cotyledon attachment is the **epicotyl** (EP ih KAHT ul) or *plumule.* The epicotyl has one or two tiny, completely formed leaves.

Seed germination

Germination, the beginning of the growth of an embryonic plant within a seed, happens only when three conditions are met:

- *Proper moisture* Many seed coats need moisture to cause them to swell and burst, thereby supplying moisture to the embryonic plant inside. If the embryonic plant were to begin to grow without adequate moisture, it would soon wither and die. Some seeds must be saturated; others require only humid conditions.
- *Proper temperature* Most seeds require a minimum temperature.
- *Proper oxygen* Oxygen is necessary for normal cellular respiration. The embryonic plant also needs oxygen to use the food stored in the endosperm and cotyledons.

Exact amounts of moisture, heat, and oxygen necessary for germination vary considerably among species. Most seeds do not require light for germination. A seed contains enough stored energy for the embryonic plant to get its roots established and to absorb water, as well as to force its first leaves above the soil. At this time the stored food in the seed is usually depleted, and if the plant is not carrying on photosynthesis, it soon dies.

When a seed germinates, the radicle breaks through the seed coat, and the hypocotyl and epicotyl unfold. Once started, the enlargement of a seedling is usually rapid. All the cells necessary to establish the root and first leaves were formed before the seed matured. To enlarge and develop, these cells merely need to be filled with water.

Answers–Review Questions 13B-2 *(p. 336)*

1. Pedicel, receptacle, sepals (calyx), petals (corolla)
2. A stamen consists of a filament (stalk) and anther. The anther has 4 chambers containing microspore mother cells which become microspores (haploid). The microspores become pollen grains in the anther. *Note: The second part of this answer is found in a box. If the box was omitted, expect only the first part of the answer.*
3. The pistil consists of the style and the stigma. The style supports the stigma, which has a sticky surface for receiving pollen. The ovary contains ovules. When the egg is fertilized, the ovule develops into a seed. The ovaries may be superior (above the receptacle) or inferior (within the receptacle). *Note: the second part of this answer is found in a box. If the box was omitted, expect only the first part of the answer.*

*4. When pollen grains come in contact with the stigma, chemicals produced by the stigma stimulate the growth of a pollen tube. The tube nucleus is at or near the growing tip of the pollen tube, and the two sperm nuclei are located immediately behind it. The pollen tube grows down the style, enters the ovary,

Fruits

A **fruit** is a mature ovary with seeds (matured ovules) inside. Auxins formed in the pollen grain cause the ovule to form a seed. These and other hormones cause the ovary to mature into the fruit. Many fruits, however, consist of accessory parts of the flower that mature with the ovary.

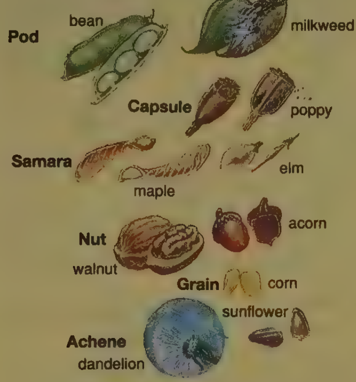
Starches, oils, and proteins stored in these structures help the plant continue its species. To do this well, the seeds must be *disseminated* (spread out). If all the seeds of a plant fell around the parent, they would compete with one another and the parent plant for light, minerals, and water.

The fruit of many plants aid seed dissemination. Fleshy fruits are often carried away by animals and man. When the fleshy portion is eaten and the seeds are discarded, dissemination has taken place. Many seeds have heavy protective coats which allow them to pass through the digestive system of an animal undamaged. Some fruits have sticky coatings or hooks which attach to passing animals. Winged fruits like the samara and seeds like those of the dandelion are carried by the wind. The seeds of many plants, like the poppy, are small and are easily carried away from the parent plant by wind or water. Some mature pods and capsules snap open, throwing the seeds away from the parent. Some plants (like the coconut palm) produce fruits that have waterproof walls and can float for long distances.

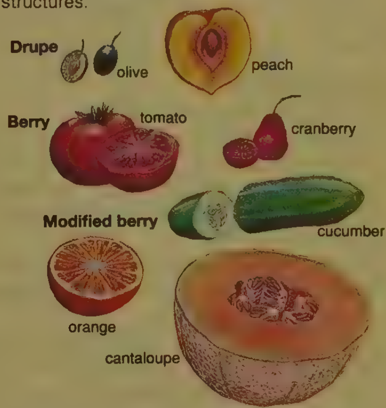
Simple

Fruits that are produced from a single ovary (even though it may have several divisions) are called simple fruits.

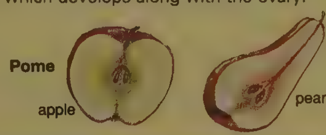
- **Dry fruits** Many simple fruits, when mature, are dry.



- **Fleshy fruits** Many fruits have thickened fleshy* parts. These fleshy parts may be the ovary, the receptacle, or occasionally other structures.



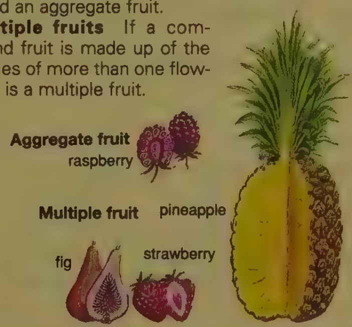
- **Accessory fruits** An accessory* fruit has some floral part (usually the receptacle) which develops along with the ovary.



Compound

Compound* fruits have several separate ovaries.

- **Aggregate fruits** If a compound fruit is made up of several separate ovaries from one flower and if these ovaries fuse, it is called an aggregate fruit.
- **Multiple fruits** If a compound fruit is made up of the ovaries of more than one flower, it is a multiple fruit.



*Many compound fruits can be considered fleshy and accessory fruits.

This box contains supplemental material which should be studied by most students. Omit this if time is limited.

There are no terms in this box which are listed at the end of the chapter; however, be sure to inform students if they are expected to learn the various kinds of fruits.

Visual 13B-3 is the *Key to Common Fruits* as found in Laboratory Activity 13. Consider using the visual of the key when dealing with sample fruits.

and then enters the ovule by way of the micropyle. The tube nucleus then disintegrates, and one sperm nucleus fuses with the egg cell, which is one of eight haploid nuclei. Five of the haploid nuclei disintegrate; the remaining two fuse together, and then fuse with the second sperm nucleus to form a triploid nucleus. The triploid nucleus forms the endosperm, which stores food for the embryonic plant. Thus, seed formation requires double fertilization–fertilization of two nuclei in an embryo sac by two sperm nuclei.

5. **(1)** The testa, or seed coat, may be smooth; it may be tight- or loose-fitting. Some seeds have extensions of the seed coat (wings) to aid in dispersal. The hilum is the point at which the seed is attached to the ovary wall. The micropyle is a small gap between integuments in the hilum region. The cotyledon serves for food storage; it may be monocot or dicot. **(2)** An embryonic plant consists of the hypocotyl, or embryonic stem (the part below the point where the cotyledons attach); the radicle, the end of the hypocotyl which develops into the primary root; and the epicotyl, the part above the point of cotyledon attachment, which has one or two completely formed leaves.
6. **(1)** Proper moisture; **(2)** proper temperature; **(3)** proper amount of oxygen

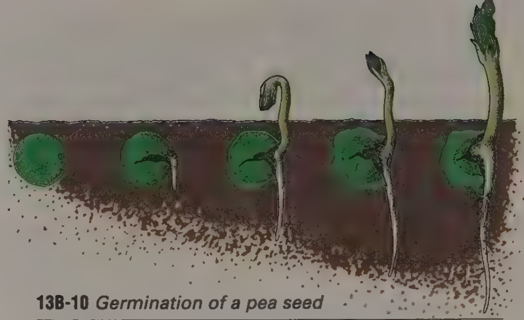
*7. **(a)** Simple fruits are produced from a single ovary, but compound fruits are produced from several separate ovaries. **(b)** Aggregate fruits are compound fruits from several ovaries of one flower that have fused together; multiple fruits are compound fruits from ovaries of more than one flower. **(c)** Fleshy fruits are fleshy at maturity; dry fruits are dry at maturity.

*8. See page 335.

*From a box.

viable: via-, vit-, or vita- (life)

Seeds sold for agriculture are tested for viability–the ability to germinate. Law requires that a certain percentage of the seeds must be viable, or they cannot be sold. Viability test results are often printed on the seed package.



13B-10 *Germination of a pea seed*

Seedlings should not be exposed to dry conditions once germination has begun, for most of them do not have enough stored food to stay alive very long. When the cells have enlarged and the cell walls have become established, the meristematic areas will form strengthening and protecting tissues, and the plant will be able to support itself even during periods of dryness.

Seeds produced in the fall usually must go through a period of dormancy before they can germinate. For some seeds this dormancy may be broken by a period of cold; others require scraping of the seed coat, and some require water to wash away inhibiting chemicals from the seed coat. If kept cool and dry, seeds may remain **viable*** (VYE uh bul) (able to germinate) for many years. The embryonic plants in seeds use stored food to maintain life during dormancy.

If they do not get oxygen, the stored food cannot be used, the embryo will die, and the seeds will become *inviable.* Some seeds, especially those produced in the spring, germinate without periods of dormancy.

Biological Terms

sexual reproduction
vegetative reproduction

Vegetative Reproduction
plantlet
runner
layering
stem cutting
leaf cutting

Sexual Reproduction
pedicel
receptacle
sepal
petal
stamen
filament
anther
pollen grain
pistil
stigma
style
ovary
ovule
micropyle
endosperm
seed
hilum
cotyledon
hypocotyl
radicle
epicotyl (plumule)
germination
fruit
viable

Facet
grafting
scion
stock
budding

Answers begin on page 334.

Review Questions 13B-2

1. Name the accessory flower parts.
2. Name and describe the male reproductive structures of a flower.
3. Name and describe the female reproductive structures of a flower.
4. Describe the process of fertilization in flowering plants.
5. List and tell the functions of the basic parts of a seed. List the basic parts of the embryonic plant within the seed.
6. What three conditions must be met in order for a seed to germinate?
7. Compare and contrast (a) simple and compound fruits, (b) aggregate and multiple fruits, and (c) fleshy and dry fruits.
8. Describe and give an example of each of the following fruits: drupe, pome, berry, modified berry, pod, capsule, samara, nut, grain, and achene.

Facet 13BF-1: Grafting and Budding, page 333

1. Describe the grafting process. How does this differ from budding?
2. Why is it important to match up the vascular cambiums of the stock and scion?
3. How can dwarf plants be produced by grafting?

Thought Questions

1. Why does the stock of a graft not affect the type of fruit and flowers the scion produces?
2. Why are some commercially valuable plants like fruit trees and Irish potatoes reproduced asexually, while others like corn and wheat are not?

Answers–Facet 13B-1

1. A stem section, called the scion, is cut off one plant and placed in contact with the stem of a rooted plant, called the stock. In time, they will grow together. In budding, a bud from one plant is used instead of a stem section. The bud is usually placed under the bark.
2. It is important to line up the vascular cambium so that the xylem and the phloem of the scion and stock can eventually join together. The cells produced by the vascular cambium can then differentiate into xylem and phloem to connect and nourish the two stems. Eventually, covering tissues will form, and the scion will grow on the stock.
3. If the stock is slow growing, then the scion may not grow as rapidly as it normally would.

Answers–Thought Questions

1. The stock contributes only water and minerals to the scion; the genes of the stock do not influence the type of flowers and fruits produced by the scion. Those characteristics are determined by the genes of the scion.
2. Corn and wheat are annual plants that do not form rhizomes, bulbs, or other storage stems. When corn and wheat fruits are mature, the entire plant dies. Also, grafting is impossible and impractical with annual monocots because the entire plant dies each season. It would be interesting to observe a Kansas wheat farmer attempting to graft the millions of wheat plants on his 640-acre farm.

Additional Notes to Teacher's Edition

Answers–Visual 5B-3b *(p. 130)*

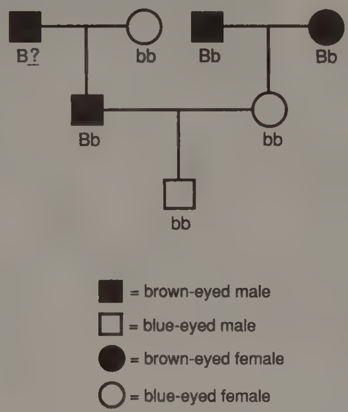
B = brown, *b* = blue

1. Man *bb* × woman *Bb* (*b* from her father, *B* from mother). Half of the children should have blue eyes.

	B	b
b	Bb	bb
b	Bb	bb

2. Man *B*_?_ × woman *bb*. Ten children–all *Bb* (*B* from father, *b* from mother). Man is probably *BB*. Eleventh brown-eyed child makes it more probable that the father is *BB*. If the eleventh child is blue eyed, the father must be *Bb*.

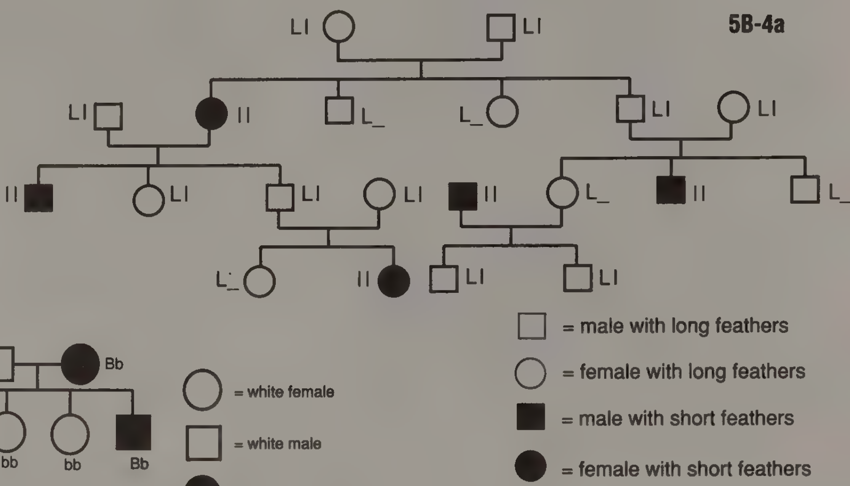
3.

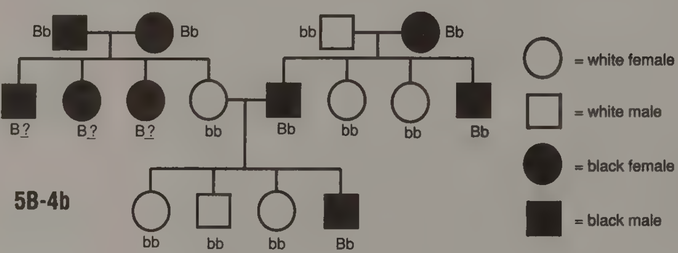


Answers–Visuals 5B-4a and b *(p. 121)*

The long-feathers trait is dominant (which can be determined by looking at the top two levels of the pedigree). The parents do not have short feathers, but they do have a short-feathered offspring. They have a phenotype which their offspring does not have. In simple dominant and recessive cases (involving a single set of alleles), in order to have parents with the dominant phenotype and yet have an offspring with the recessive phenotype, the parents must be heterozygous. Because the middle two offspring of the first cross do not have offspring and have the dominant phenotype, one cannot be sure of their genotypes. Students may want to suggest that they are heterozygous. Remind them that each offspring has a 1-in-4 chance of being any one of the possible gamete combinations in the Punnett square. One cannot tell which is which by merely looking at the phenotypes. The far right offspring of the original cross is heterozygous, but this is known only by looking at its offspring, not by looking at it or its parents.

5B-4a





5B-4b

Answers–Visual 5B-5 *(p. 131)*

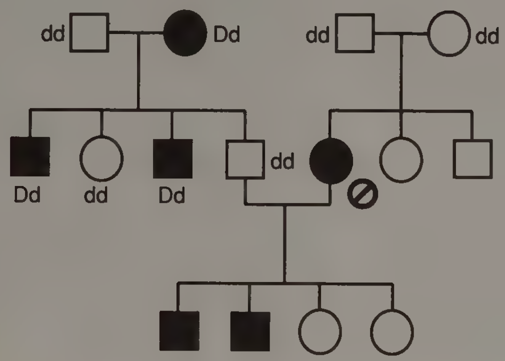
The shepherd could perform test crosses by mating the ram with several dark ewes. The dark ewe must be homozygous recessive *(ww)*. If the ram is homozygous *(WW)*, all the offspring will be white. If the ram is heterozygous *(Ww)*, about half of the offspring would be dark. Any dark lambs from this ram would be sufficient for the shepherd to get his money back.

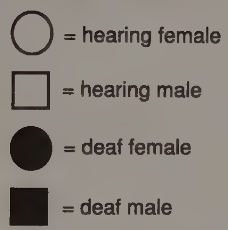
	w	w
W	Ww	Ww
W	Ww	Ww

	w	w
W	Ww	Ww
w	ww	ww

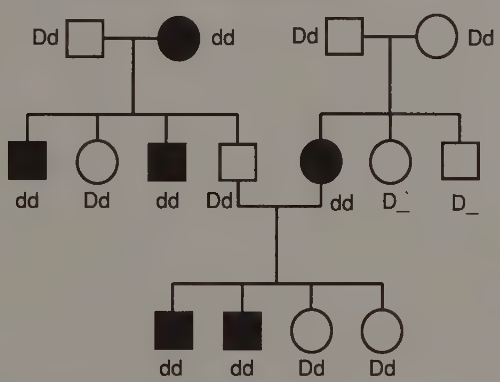
Answers–Visual 5B-11 *(p. 141)*

1. Dominant autosomal characteristic:

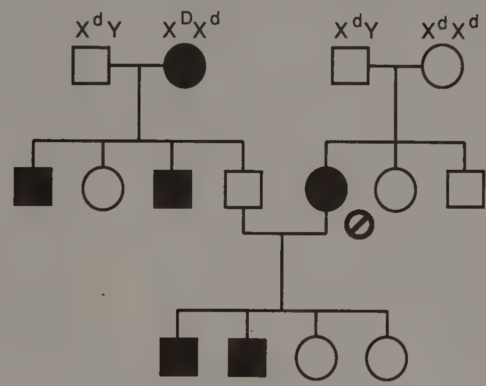




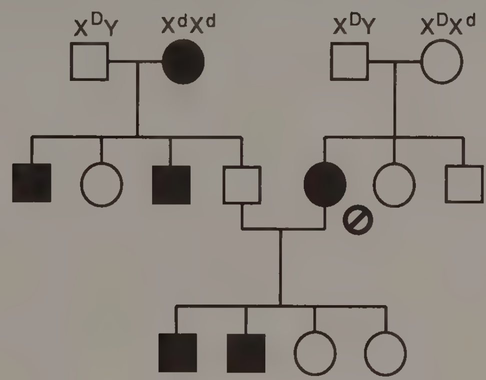
2. Recessive autosomal characteristic:



3. Sex-linked dominant characteristic:



4. Sex-linked recessive characteristic:



5. A Holandric (on *Y* chromosome) characteristic:
   Impossible. Only men would have the characteristic since only men have the *Y* chromosome. Women do have this form of deafness.

The Germ Theory of Disease *(p. 245)*

The germ theory of disease might serve as an interesting point of discussion. This theory, which states that many diseases are caused and spread by specific pathogens, was not always accepted. It is difficult to demonstrate conclusively that a particular bacterium, for example, causes a certain disease. The first important experiments of this nature concerned anthrax, a disease which affects animals such as sheep and cattle and occasionally affects humans. Capable of wiping out entire herds and proving fatal to many farmers and wool handlers, anthrax was often called ''wool sorters' disease.''

In the 1870s Robert Koch, a German physician, examined animals that had died of anthrax. When he studied their blood under a microscope, he saw large numbers of bacillus bacteria. He suspected that these bacteria were the agents that caused the disease, but how could he prove it? He inoculated a mouse, opening its skin and exposing the wound to some of the bacilli from the blood of a dead animal. The mouse soon contracted anthrax and died. Koch then examined its blood and found that the bacilli had greatly multiplied.

Koch had to be sure it was the bacilli, and not some blood chemical, which caused the disease. He needed the bacteria in a blood-free condition. Koch made a laboratory culture by placing a few of the bacteria in the sterile liquid he took from the eyeball of a freshly killed ox. The bacilli grew and multiplied in this medium. He repeated the process several times to be sure he had only the bacteria and no blood in his culture.

Koch then used these blood-free bacilli to inoculate healthy mice; they contracted anthrax and died. The blood of these mice also contained the bacilli in large numbers. He concluded that the rod-shaped bacteria were the anthrax pathogens. Koch completed this work in 1876. It was but the first of several major contributions that led to his being called the ''father of bacteriological techniques,'' to his receiving a Nobel Prize (1905), and to the acceptance of the germ theory of disease.

Strains of anthrax can be used in biological warfare. For standard anthrax, antibodies are effective; for some of the virulent strains cultured for warfare, there are no known effective treatments. However, immunity is possible for some forms of anthrax.

Appendix A

A History of Scientific Thinking

It is easy to point to the beginning of science. Adam was the first biologist: he tended and dressed the Garden of Eden and named the animals (Gen 2:15, 19-20). However, we do not know the processes which Adam used. Did he group the animals and give them names within the groups? What botanical knowledge was involved in caring for the Garden, and how did Adam obtain the knowledge? We have no way of knowing.

We, likewise, have very little way of knowing the scientific processes used by most other Biblical characters or ancient peoples. On rare occasions God gave certain people specific skills for special purposes (Ex. 35:30-35). Presumably they taught others this knowledge. With these exceptions, the Bible tells us only that some people had knowledge of certain skills (Gen. 4:20-22; I Chron. 15:22; II Chron. 2:13-14); it does not tell us how they obtained this knowledge.

We know that ancient people had various kinds of scientific knowledge (such as how to build a pyramid, grow certain crops, make certain metals, calculate the seasons, etc.). We do not know how much of this knowledge was passed on to them or what methods they used to discover these things. Although much of their scientific knowledge was accurate and impressive, much of what they thought they knew was inaccurate. For example, ground- up pearls do not help people bear children, nor does mustard on the nose cure deafness.

Today, both Christians and non-Christians assume that the scientific method is a good way to determine valid, workable solutions to many physical problems. This has not always been the case. As you consider how people in different ages have determined what they thought was true regarding the physical world, you will understand better what a Christian should believe regarding the relationship between science and the Scripture.

The ancient Greeks

The Greek culture flourished about 500 yr. before Christ. Although known for sculpture, architecture, and literature, the most significant Greek contribution to society was *philosophy*. Philosophy is a system of values which affects how a person thinks and what he does. The ancient Greeks were "natural philosophers" because they sought logical explanations of nature. They wanted to explain physical phenomena without resorting to supernatural explanations, such as "the gods did it" or "an evil spirit caused it."

Anaximander's "boundless" is one of the earliest forms of evolutionary theory. It is too bad his evolutionary philosophy did not end up in the same place as his "boundless" theory. The same observations that defeat one, defeat the other.

Anaximander (uh NAK suh MAN dur) (ca. 500 B.C.) imagined a physical substance called "boundless" which made up all things. "Boundless" was a concept that stated that something was slowly becoming: this something used to be something else, but now it is what we can experience with our senses; and it is "boundless" in what it can become. Anaximander realized that his speculations needed observations to back them up, but he also believed that making observations was not a philosopher's job. Because he felt observations were needed to support his theory, Anaximander is called "the Father of Science" even though his "boundless" theory was forced into the philosophical "junk heap" due to the lack of observable proof.

Empedocles (em PEHD uh KLEEZ) (ca. 425 B.C.) changed "boundless" into four substances which he called *humors* (fluids): fire, air, water, and earth. Different combinations of these humors made up everything from matter to weather, and living things consisted of special forms of these humors. Empedocles' concept was later known as the Doctrine of Humors.

Hippocrates (ca. 400 B.C.), a physician-philosopher, used the four humors idea to explain sickness and health (see pages 4-5). The idea that physical health is controlled by a mixture of four fluids seems unscientific today. Before Hippocrates, however, most people believed that sickness was caused by evil spirits and that good health was a result of pleasing the gods. Because he explained health and sickness in natural rather than supernatural terms, Hippocrates is called "the Father of Modern Medicine."

As far as science is concerned, one of the greatest of the Greek philosophers was *Aristotle* (ca. 350 B.C.). Aristotle believed that reality (that which is true) was found in nature, not in some far-off ideal as some of his predecessors had claimed. Since reality is the objects, to know truth one needs to know the objects. To Aristotle, if someone observed, grouped, and described natural phenomena, he could arrive at the truth about them. Aristotle was an early biologist because he described and grouped over 500 organisms.

Paul speaks of the Greeks seeking wisdom but says that God will "destroy the wisdom of the wise and bring to nothing the understanding of the prudent." Even today, those who look for explanations of physical phenomena and ignore the God who created all things lack true wisdom. Christians who believe in the truth of Christ, which is "to the Greeks foolishness," recognize that Christ is the power and wisdom of God (I Cor. 1:18-24).

Science of the Romans and the early Christians

Rome conquered Greece and then "borrowed" Greek culture and philosophy. Most of the Roman scientists were like *Pliny* (PLIHN ee) (ca. A.D. 50) who wrote a 37-volume encyclopedia of real and fictitious descriptions of physical phenomena. Many of these descriptions were based on stories of travelers; only a few were the direct result of Pliny's own observations.

Galen (ca. A.D. 175) was a Roman physician (see page 551) who believed the Doctrine of Humors; dissected sheep, apes, and other large mammals; and applied his

A History of Scientific Thinking

This section is designed to reinforce what the scientific method is and what its limitations are. By looking at historical development of scientific thought in relation to religious thought (not necessarily Scriptural thought), one can better see what current beliefs are and can recognize their strengths and weaknesses. This section is designed to be a survey, not a major analysis. Great care must be taken when teaching this material to avoid reducing it to a dozen facts to be memorized. An understanding of the development of and an appreciation for the present scientific philosophy should be the goal.

The material is designed to complement the content of Chapters 1A and B. Because of their backgrounds, certain students (or teachers) may have difficulty with this material. If the difficulties are severe, this section should be omitted. Consider requiring students to read the material (possibly answering the questions at the end of the section), spending only 10-15 minutes in class, and not covering it on the test. This will expose the good students to these concepts but not overburden the less gifted who will probably not need them.

For schools that offer two years of high school biology, this section, with adequate supplemental material, can serve as an introductory study in the second course. The scientific method and the limitations of science can be reviewed and expanded using this material.

observations to humans. His observations led to some accurate conclusions and some inaccurate ones. For example, he said that the liver made blood, which the heart warmed and sent out through the blood vessels.

A stated Christian philosophy of science from this period is difficult to find. Most Christians were too busy with more pressing problems than scientific pursuits. The periodic persecutions by the Romans not only kept the Church strong but also left its members little time for significant scientific activities.

In A.D. 313 the Emperor Constantine embraced Christianity, which in time became the state religion. By then, however, political Rome was in decline, and a short time later it was completely destroyed. The "official church" (the Roman Catholic church) stepped in to become not only a religious organization but also a form of government. Some of its beliefs and practices were based on what was best to maintain its political control rather than what was Scripturally correct.

The Dark Ages and scholasticism

The time between the 5th and the 9th centuries is sometimes called the Dark Ages because during this time culture and science stagnated. Only a few of the nobility and some of the church leaders were educated. It was relatively easy for the educated minority to keep the ignorant in submission with tales and threats.

One concept they found convenient was a perversion of the doctrine of faith. A person's salvation is all of faith in Christ's atoning death on the cross; however, they went so far as to say that everything should be of faith. This grew to mean that there is no truth outside of Scripture. Thus, knowledge of sacred things was considered good while knowledge of physical things was considered "worldly" (meaning both "of the physical world" and "of the sinful world"). If a person had an abundant knowledge of physical phenomena, he must have been very worldly, perhaps a sorcerer or witch. He was, perhaps, a dealer in the "black arts" and in league with the "prince of the power of this world," Satan himself. A philosophy that equated knowledge of the physical world with evil made it a truly dark age for science.

In time, the absurdity of this philosophy became apparent, and even the Roman Catholic church began looking beyond Scripture for knowledge of the physical world. Scholars rediscovered the writings of the ancient Greeks and in doing so created much controversy. Many recognized the Greeks as anti-God in that they tried to explain everything in "natural terms" and did not wish to recognize a supernatural God. Others believed that the Greek writings were an interesting new source of knowledge.

Thomas Aquinas (uh QWINE us) (ca. 1200), a Catholic theologian-philosopher, developed strong arguments supporting the idea that Aristotle and Scripture did not contradict each other. Aristotle was, of course, a pagan and also erred in many of his observations and conclusions. "The Philosopher" was the name that Aquinas gave to Aristotle, and in order to justify and "Christianize" him, Aquinas often misrepresented Aristotle and even occasionally contradicted the Bible.

The practice of seeking truth in ancient writings, along with Scripture, and the teachings of the Roman Catholic church is called *scholasticism* (skuh LASS tuh SIZZ uhm). Scholastics even believed that if some point of knowledge were not revealed by the ancients or Scripture, it was either not worth knowing or could not be known.

An Example of Scholastic Thought

The following anecdote shows how scholastics thought problems should be solved:

> In the year of our Lord 1432, there arose a grievous quarrel among the brethren over the number of teeth in the mouth of a horse. For thirteen days the disputation raged without ceasing. All the ancient books and chronicles were fetched out . . . [and consulted]. At the beginning of the fourteenth day, a youthful friar . . . asked his learned superiors for permission to add a word, and straightway, to the wonderment of [all] . . . he beseeched them . . . to look in the open mouth of a horse and find answer to their questionings. At this, their dignity being grievously hurt, they waxed exceedingly wroth; and . . . they flew upon him and smote him hip and thigh, and cast him out forthwith. For, said they, surely Satan hath tempted [him] to declare unholy and unheard-of ways of finding truth contrary to all the teachings of the fathers. After many days more . . . [they declared] the problem to be an everlasting mystery because of [lack] of historical and theological evidence thereof, so ordered the same writ down. (Francis Bacon, cited by C.E. Kenneth Mees in "Scientific Thought and Social Reconstruction," *Electrical Engineering*, March 1934, pp. 383-84.)

Aristotle, who was probably one of the ancient writers consulted, would have agreed with the procedure suggested by the friar.

One argument the scholastics used to support their looking to old writings for knowledge used this logic:

- Adam was perfect before he sinned.
- Part of being perfect is to know all things.
- When Adam sinned, he was no longer perfect.
- When Adam was not perfect, he began forgetting things he had known.
- Adam's offspring could not know things Adam had forgotten.
- The more generations one is removed from Adam, the less is remembered.
- The ancient writers were many generations closer to Adam than we are.
- Thus, the ancient writers know more about things than we do.

In Catholic dogma, prohibiting the laity from reading the Scripture because they would misinterpret it made good political sense. Keep the peasants ignorant, and they will believe anything they are told. It is only within the last 100 years that Catholics have been permitted to read the Bible.

Similar arguments were presented for intelligence and even ability to know. Ask students to demonstrate the faulty reasoning in these "logical" statements. A good argument can be presented against most of them.

Ask students whether they know any passage that could be used to support the idea that the sun moves around the earth? *(Joshua 10:12-14, in which Joshua commands the sun to stand still, is the best known.)* The passage says the sun stood still upon Gibeon and the moon stood still in the valley of Ajalon. Did these two heavenly bodies literally come and "stand" on these two features of the earth? *(The sun and moon stayed still in the heavens above these two places.)* This is exactly how it would have appeared to Joshua when the earth stopped moving. It was not necessary to say that the earth stopped turning so that the sun appeared to stand still. God had Joshua record what he saw, which is more than enough to attest to the miracle. The primary teaching of the passage is the miracle God performed in support of His people. It is not a lesson in astronomy. Using the passage to teach the placement of heavenly bodies is to use it out of context.

Note that God sent His Son into a sinful world, a fact which is far more significant than sending Him to a planet that is not in the middle of something. The purpose of Christ's coming is far more important than the location of the earth to which Christ came. This is another example of using Scriptural teaching (God's perfection) out of context to deal with physical things.

It is interesting to note that the position of many of the Protestant reformers favored the geocentric system supported by the ▶

The awakening of science

The age of scholasticism was not without its critics. *Roger Bacon* (ca. 1250) was an English, Franciscan monk who had a few chemicals and some crude apparatus. To satisfy his curiosity, he conducted some experiments and wrote about the results. He was accused of witchcraft and other related evils, tried, condemned as a heretic, and imprisoned for his crime. In his papers he claimed that observation and experimentation were better methods for understanding nature than blind devotion to the past.

Although ahead of his time, his voice was heard. During the 1500s and 1600s many people found more fault with the ancients and began to look to their own ability to solve problems. The awakening of science began when people stopped looking to the past and started trying to figure things out for themselves.

It was one thing to question the authority of Aristotle and demonstrate his errors in light of observation. It was quite another to challenge the Roman Catholic church, which claims to have Divine guidance and authority. A major controversy developed over the belief that the earth was the center of the universe. Using ancient writings and a couple of Scripture passages that do not directly deal with the topic, the Catholic church taught that the heavenly bodies rotated around the earth. Some even used logic to support this belief: a perfect God would not send His sinless Son to a planet that was off center.

Galileo (ca. 1600), a respected Italian scientist, had studied the physics of falling bodies, tried to describe light, and used the newly invented telescope to observe the night sky. In one of his early books, Galileo denounced the scholastic view saying that those who look only to the ancients were acting as if "nature had written this great book of the world to be read by none beside Aristotle."

Galileo, after many observations and calculations, wrote an interesting and popular book which stated that the sun was the center of the universe, and the earth and other planets revolved around it. Galileo was warned by church officials that he was bordering on heresy: the church was right because of its great authority, and his observations or calculations could easily be inaccurate. He was warned to keep quiet about this matter unless he had "undeniable proofs." Galileo was sure of his observations and calculations, and, with the blessing of some in the church, continued to write about the earth going around the sun.

Galileo, a loyal Roman Catholic, defended his position, saying that "The book of nature and the Scriptures have the same author." In other words, accurate observations of the physical world will not contradict the Scripture since both were created by God. Galileo wanted the church leaders to change their opinions regarding what they believed the Scripture said. The controversy was not so much over whether the sun or earth was at the center of the universe, but whether the church had the right to interpret Scripture and force reason, logic, and observations to go along with its interpretations.

At the time, the Roman Catholic church was troubled by what it considered the heresy of the Protestant reformers. Since Galileo was a well-known scientist, the church could not tolerate his rebellion against church authority. To do so would have seemed like weakness and would have encouraged others to challenge the church. Thus, Galileo was summoned before a church tribunal and told that if he did not recant, the church would condemn him to death and hell as a heretic. Galileo, at this time an old, blind, and sick man, recanted and agreed to not spread his heresy. The church was merciful; it did not imprison him but, instead, confined him to his house for the rest of his life.

Some believe that at his recantation, Galileo, after disavowing that the earth went around the sun, got up from his knees and said under his breath, "But it does." Although somewhat in keeping with Galileo's character, it is doubtful that he did this. It is also doubtful that Galileo really believed what he was forced to say. It was 300 yr. later (in the 1980s) that the Roman Catholic church changed its position regarding the universe and recognized that Galileo had been right.

Experimental biology

Biology, because it deals with living things which are more difficult to measure and experiment with, is often far behind the physical sciences. Although he was ahead of his time, *William Harvey* (ca. 1615), an English physician, introduced observation and experimentation into the biological sciences.

While Galileo was observing the heavens, Harvey was observing the human heart and blood vessels. He respected the ancients and often cited them in support of what he believed. He also believed that experimentation, observation, and reason could prove them wrong. Galen's theories about the heart and circulation had been the basis for medical practice for over 1,400 yr., but to Harvey, they did not make sense.

Harvey observed that the valves of the heart permitted blood to flow only in certain directions, not back and forth. He observed that blood which leaves the heart goes only into certain blood vessels (arteries). Other blood vessels (veins) have valves in them which permit blood to flow only toward the heart. He also demonstrated that there were no holes in the wall between the two sides of the heart (needed for Galen's theory to work). He measured the amount of blood forced from the heart in a single beat and then calculated how much blood would have to be made in order to keep the heart pumping. It is impossible for a body to contain that much blood.

Based on his observations and experiments, Harvey described the *circulation* of the blood. A complete theory of blood flow lacked only an explanation of how blood moves from the arteries to the veins. He speculated about tiny blood vessels which attach arteries and veins and demonstrated that they must exist. But since the microscopes available to him were not strong enough to see the

Answers–Review Questions

1. Seeking a natural philosophy, the Greeks wanted to explain physical phenomenon without resorting to supernatural causes. They believed reality could be discovered by observing things.
2. Knowledge was to be found in looking at ancient writings and Scripture. Observations and experimentations were not to be used.
3. He would not. His animal observations may or may not have been valid when compared to humans. His conclusions regarding the liver, heart, and blood, for example, were in error.
4. Since Adam was perfect, he must have had perfect (all) knowledge. His descendents are progressive steps away from his perfection; thus, they know less and less. If modern man wants to know truth, he should look back to those who know more than he does because they are closer to the perfect knowledge of Adam.
5. **(a)** Anaximander, an ancient Greek, believed in "boundless" but suggested that observations were necessary to back up this belief. He was called the "Father of Science." **(b)** Aquinas, a Roman Catholic theologian-philosopher of the Dark Ages (ca. 1200), tried to harmonize observations of Aristotle and the Scripture. **(c)** Aristotle, an ancient Greek, believed that observations of reality were the way to know truth since truth was reality. **(d)** Roger Bacon, an English Franciscan monk of the Dark Ages (ca. 1250) who conducted experiments and was tried as a heretic, advocated that observations were better than blind obedience to the past.
(e) Empedocles, an ancient Greek, believed all matter came from four humors. **(f)** Galen, a Roman physician who lived about 175 years after Christ, believed that the liver made blood which the heart warmed and sent out

tiny capillaries, he could not observe them. Because of his pioneering work, Harvey is often called the "Father of Experimental Biology."

Harvey was heavily criticized and a number of his colleagues were rude to him because of his beliefs. However, he was not imprisoned or threatened with death and hell for his scientific work and beliefs. England was no longer under the control of the Roman Catholic church, and the intellectual world was turning its back on scholasticism.

The Age of Modern Science

Although Bacon, Galileo, and Harvey were at the forefront of scientific developments, many other scientists followed their example. By the 1800s the scientific method was the primary method of learning about the physical world. The ancient Greeks are still considered as wise masters of many things, but it is laughable to cite them as scientific authorities.

Man's use of science has flourished. Observation and experimentation have allowed man to be able to control many aspects of the physical world. Diseases have been conquered; abundant food, clothing, and comfortable housing have been supplied; and, in general, life has been made easier through scientific advances. Science has become man's tool to supply his physical needs with less effort.

But where does God fit? For many, He does not. Today, some people look to science for everything. To them, man will improve through science. In fact, science is man's only hope of ever improving. This is *scientism,* the worship of science. A Christian, however, knows that science cannot make a man truly good. Only Christ can forgive sin; only Christ can give him the strength to live a life that is pleasing to Him.

Scientism is quite similar to the "natural philosophy" of the ancient Greeks. They sought to explain natural phenomena without resorting to supernatural explanation. Those who believe in scientism refuse to recognize God as Creator and Sustainer of the physical world and as the only Saviour of men. (See Chapter 1A and B for a modern definition and philosophy of science and pages 25-29 for a Christian philosophy of science.)

Few people would admit to believing "scientism." Anyone who is a humanist, however, is a practical believer in "scientism."

It is interesting to speculate how God sees all this. Today's scientists are probably making just as many "stupid" mistakes as the ancient Greeks.

Review Questions

1. Describe the scientific philosophy of the ancient Greeks.
2. Describe the scientific philosophy of the scholastics.
3. Would Galen be considered a good scientist today? Why?
4. On what basis did the scholastics base the idea that the ancients knew more about natural phenomena than they did?
5. Identify the following as to historical period and contribution to scientific thought: (a) Anaximander, (b) Aquinas, (c) Aristotle, (d) Roger Bacon, (e) Empedocles, (f) Galen, (g) Galileo, (h) William Harvey, (i) Hippocrates.
6. What was the crime that brought Galileo before the Roman Catholic tribunal?
7. Describe William Harvey's work and its significance.
8. Of the men listed in question 5 which holds a position most like the Christian philosophy of science described in Chapter 1 (especially pages 9, 12, 25-29)? Explain your answer.

▶ Catholic Church against the heliocentric system. To them the literal interpretation of the Bible seemed to demand that the sun go around the earth.

Copernicus, an earlier scientist, had also concluded that the sun went around the earth. His observations were not made with a telescope, and he had carefully stated his position as theory and subject to the teachings of the Church. His book was published after his death.

(no circulation). **(g)** Galileo, an Italian scientist of the 1600s, made observations regarding the earth's going around the sun and was persecuted by the Church for his belief. **(h)** William Harvey, an English physician of the 1600s, is known for his observations of the flow and circulation of the blood which contradicted Galen. Harvey is called the "Father of Experimental Biology." **(i)** Hippocrates, an ancient Greek physician, believed in the doctrine of Humors. Since he believed sickness and death were the result of natural causes, Hippocrates is called the "Father of Modern Medicine."

6. His observations told him the earth revolved around the sun, which was contrary to the teachings of the Church. Galileo was tried for the heresy of contradicting a teaching of the Roman Catholic Church.
7. Harvey conducted experiments that demonstrated that the flow of blood made a circuit in the body. He showed that the heart pumps blood into arteries and that the blood returns to the heart by way of the veins. His calculations refuted Galen's idea that blood was formed from food in the liver.
8. It was probably Galileo; however, an argument can be made for William Harvey. Galileo's concept that what truly exists in nature will not contradict God's Word is one of the major tenets of a good Christian philosophy of science.

Appendix B

A Modern Classification System

Listed below are the major divisions of the classification system along with their main characteristics, examples, and their location in this book. This listing is to be used for summary and review of the text material. Several additional divisions and examples are listed for reference purposes. The classifications are presented in the order they are covered in the text with supplemental classifications listed alphabetically unless otherwise noted.

The term *phylum* is used for uniformity throughout this classification system. The term *division* is technically correct in the kingdom Plantae and is sometimes used in the kingdoms Monera, Protista, and Fungi.

Kingdom Monera[1] (Chapter 9)

Cellular Structure
- Cells procaryotic (lack organized nucleus; lack membrane-bound organelles)
- Most have cell walls with capsules or sheaths; unicellular or simple colonial organisms

Nutrition
- Most heterotrophic; some photosynthetic; some heterotrophic and photosynthetic; some chemosynthetic
- Some parasitic
- Some pathogenic
- Most use oxygen when available but can also carry on fermentation; some require oxygen; some carry on only fermentation

Reproduction
- Simple fission (forms of genetic recombination are known in some species)
- Some form endospores

Motility
- Many nonmotile; some motile by simple flagella; some have gliding movement

Subkingdom Eubacteria (The True Bacteria)

Phylum Gracilicutes

Thin cell walls that stain Gram-negative (pages 226-36)
Many true bacteria: *Escherichia coli, Salmonella;* phototrophic bacteria
Cyanobacteria (blue green algae): *Nostoc, Oscillatoria, Anabaena* (page 233)
Rickettsias (page 234)
Spirochetes (page 235)

Phylum Firmicutes

Thick cell walls that stain Gram-positive; many form endospores (pages 226-36)
Many true bacteria: *Bacillus, Staphylococcus, Streptococcus*

Phylum Tenericutes

Lacks cell walls (page 235)
Mycoplasmas

Subkingdom Archaebacteria

Phylum Mendosicutes

Unusual cell walls and capsules; makes methane gas; lives in very salty or hot, sulfurous environments; many have unique metabolic pathways
Methanobacterium

24–Human Reproduction

(continued from p. 627)

few parents, youth workers, or pastors are able to do. Any thorough study of biology must include a study of the reproduction of organisms. At what better point could the structures of human reproduction be presented? In biology class, both teacher and student have been talking about ova, sperm, fertilization, genes, hormones, and placentas in detail which few parents or pastors are able to discuss. This is the ideal time to present the facts of human reproduction, and, if the subject is handled properly, expel some of the wrong views the students may have.

The Bible clearly teaches that sex is not wrong or dirty. The Song of Solomon and other passages that deal with the relationship between husband and wife clearly teach that the sexual relationship within the bonds of marriage is part of God's will. However, the Bible is equally clear that God vehemently condemns those who engage in sexual perversions and those who commit adultery and fornication. Some adults, in an attempt to keep children "pure," may overemphasize these forbidden activities, pointing out that they are "wrong, dirty, and sinful" to the extent that the young person winds up with a warped view of sex.

By the time a young person reaches his teen years, he is making certain decisions for himself regarding sexual relationships with others. God, in His wisdom, has ordained that the body mature during the teen-age years, forcing the person to make such decisions. A normal, well-informed young person with proper guidance can make proper choices. Recall that God will not tempt the Christian beyond that which he is able to bear; He will not present an opportunity to make a decision without also providing a way for the right decision to be made. If he knows the facts, a person who wants to do right, can. An ignorant person, however, is easily led astray.

Kingdom Protista (Chapter 10)

Cellular Structure
- Cells eucaryotic (have an organized nucleus and membrane-bound organelles)
- Many unicellular, many are colonial; some form large multicellular structures; none have tissues

Nutrition
- Some heterotrophic (either ingesting material or absorbing substances); some are photosynthetic; some can be either heterotrophic or photosynthetic
- Some parasitic
- Some pathogenic

Reproduction
- Most carry on simple fission
- Colonies often reproduce by fragmentation or budding
- Many have sexual reproduction either by conjugation or gametes

Motility
- Many float, others sessile (grow attached to surfaces)
- Many move by cilia, flagella, or pseudopods

Subkingdom Protozoa[2] (Chapter 10A)

Motile in at least one phase of its life cycle; heterotrophic (some are heterotrophic and photosynthetic)
"Animallike" protists, protozoans

Phylum Sarcodina[3]

Unicellular; no pellicle; moves by pseudopods; heterotrophic (engulfs food by phagocytosis); some form tests, some form cysts; reproduction usually by fission; salt water and freshwater forms; some parasitic, some pathogenic (pages 260-63)
Sarcodines: ameba, foraminiferans, radiolarians

Phylum Ciliophora

Unicellular; has pellicle; moves by cilia; heterotrophic; some form cysts; many have macronucleus and micronucleus; salt water and freshwater forms; some parasitic, some pathogenic (pages 263-64)
Ciliates: paramecium, stentor, *Vorticella*

Phylum Mastigophora[3]

Unicellular or colonial; has pellicle; moves by flagella; heterotrophic, but some can be either photosynthetic or heterotrophic; salt water and freshwater forms; some parasitic, some pathogenic (pages 264-65)
Flagellates: *Euglena, Trypanosoma, Volvox*

Phylum Sporozoa[4]

Unicellular, rarely colonial; no structures for locomotion; forms spores; all parasitic, many pathogenic (pages 265-67)
Sporozoans: *Plasmodium*

Subkingdom Protophyta[2] (Chapter 10B)

All are photosynthetic with chlorophyll and other pigments in plastids
"Plantlike" protists, algal protists

Phylum Chlorophyta[5]

Unicellular or colonial forms; motile, free-floating and sessile forms; food stored as starch; cell walls of cellulose; salt water and freshwater forms (pages 270-71)
Green algae: *Spirogyra, Ulothrix, Protococcus,* desmids, *Oedogonium, Chlamydomonas*

Phylum Chrysophyta

Unicellular and colonial forms; motile and free-floating forms; food stored as oils and complex carbohydrates; cell walls often contain silicon; salt water and freshwater forms (pages 272-73)
Diatoms, yellow-green and golden algae: *Vaucheria, Dinobryon*

Some people believe that if a child is sheltered, if certain facts are withheld from him, and if enough fear is put into him of even thinking about the physical changes taking place in his body, then he will be kept from sin. Few things are further from the truth. Everything from advertisements to church youth fellowships and high school functions (which encourage dating) presents the concept of male-female relationships. Adults stress the importance of building good relationships between members of the opposite sex, but in this world, sooner or later, the young person will be strongly tempted. The job of the older, more mature Christians in guiding a young person is to make sure he has enough information and enough Scriptural understanding to be able to recognize and stand against the attack of Satan.

When certain reproduction-related topics are discussed with elementary or junior high students, it is best to divide the class. The maturity level of the students prohibits covering topics of this nature with mixed company. By the time the students are in tenth grade, they should be mature enough to react appropriately in the presence of members of the opposite sex if the material is presented properly. In the younger grades the purpose of talking about human reproduction is to help the students understand what is happening to their bodies. By the time the students are in tenth grade, the emphasis needs to be broader. Some topics should be covered in separate groups, but a general presentation of the reproductive structures and human relationships on the level needed in high school biology does not warrant that separation.

Christian educators generally prefer that a teacher with reasonable classroom control present this material in a mixed class. Separation tends to increase students' curiosity at seeming "secrets" ("What are they telling the boys that they won't tell us?"). The unusual action of splitting the class exaggerates the importance of the ma-

Phylum Pyrrophyta

Unicellular with two flagella; food stored as starch or oil; mostly salt water forms (page 273)
Dinoflagellates: *Gymnodinium*

Phylum Phaeophyta[5]

Colonial (usually large thallus); sessile; food stored as oil and complex carbohydrates; cell walls of cellulose; mostly shallow salt water forms (page 273)
Brown algae: *Fucus*, kelp, *Sargassum, Laminaria*

Phylum Rhodophyta[5]

Colonial; nonmotile, usually sessile; food stored as carbohydrates; cell walls of cellulose; mostly deep salt water forms (page 274)
Red algae: *Chondrus, Lemanea, Polysiphonia*

Kingdom Fungi (Chapter 11)

Cellular Structure
- Cells eucaryotic
- Has cell walls which usually contain chitin
- Some unicellular, some colonial; some form large structures of intertwined hyphae; none have tissues

Nutrition
- All heterotrophic with external digestion
- Some parasitic
- Some pathogenic

Reproduction
- Some carry on simple fission; many form various kinds of spores
- Most have sexual reproduction by conjugation or gametes

Motility
- Many sessile, some float, a few are motile
- Some produce motile gametes

Phylum Zygomycota[6]

Hyphae are nonseptate; sexual reproduction by conjugation (pages 282-83)
Common molds: *Rhizopus, Pilobolus, Glomus, Entomopthora*

Phylum Ascomycota[6]

Hyphae are septate; forms sexual spores in an ascus; many produce asexual spores on conidia (pages 283-84)
Sac fungi: cup fungi, yeasts, fruit molds, powdery mildews, morel, *Penicillum, Aspergillus, Neurospora*
Imperfect fungi:[7] athlete's foot fungus, ringworm, thrush

Phylum Basidiomycota[6]

Hyphae are usually septate; mycelia often produce large, fruiting bodies; produces spores on a basidium (pages 284-86)
Club fungi: mushrooms, puff balls, earthstars, shelf fungi, rusts (wheat rust, apple cedar rust), smuts (corn smut)

terial. Splitting the class also takes more class time. The teacher may make a balanced presentation more naturally and easily to a mixed class. The biology teacher may find it awkward to present this material to the opposite sex. If an additional teacher is brought in, the awkwardness is merely transferred to an unfamiliar, often less-qualified teacher. The underlying message to the class is that beliefs about sex are shaky; even the leaders flounder with the subject.

In some schools, however, it may be deemed best to separate the young men and young ladies while the reproductive organs are discussed. However, while human embryology, euthanasia, abortion, and the Scriptural position on these topics are discussed, it is good to have the students together.

For nearly twenty years, I have presented the material discussed in Chapter 24 using methods similar to those suggested on the following pages. Many parents have expressed their appreciation for the fact that I covered this material. For several years I have, on my end-of-the-year course evaluation sheet, asked my students what they thought of this unit of study. Almost all of them have indicated that they learned things and saw them in a new perspective. Although some responded, "I was occasionally embarrassed a little, but not as much as I thought I would be," most remarked, "I was not embarrassed at all," and no one to my recollection has ever marked "I was very embarrassed."

Of course, to any teacher one of the most gratifying experiences is to have a young person return several years after graduation and comment on his appreciation for what he learned. Although I often get comments about this material from returning students, this one sticks out in my mind: "I am so glad you explained those things that we talked about at the end of the year. Although Dad had talked with me about it, I really did not understand what

Phylum Myxomycota[8] (Myxomycophyta)

A plasmodium (multinucleate cellular structure) that often moves with pseudopods and produces sporangia
Slime molds

Phylum Oomycota[8]

Water molds, downy mildews, *Saprolengnia*

Phylum Acrasiomycota[8]

Cellular slime molds

Kingdom Plantae[9] (Chapters 12-13)

Cellular Structure
- Cells eucaryotic
- All have tissues; most have organs
- Most have chlorophyll and other pigments in plastids
- Has cell walls made of cellulose

Nutrition
- Most autotrophic (photosynthetic), some parasitic

Reproduction
- Reproduces sexually
- Many have asexual forms of reproduction

Motility
- Most sessile, some float
- Some produce motile gametes

Part 1: Nonvascular Plants

Phylum Bryophyta

Lacks vascular tissues; plants small; no true leaves, roots, or stems; gametophyte plant dominant; sporophyte is a parasite on the gametophyte (pages 289-91)
Bryophytes

- **Class Musci** (pages 289-91)
  Mosses: *Bryum, Polytrichum, Musci*
- **Class Hepaticae** (page 291)
  Liverworts: *Marchantia*
- **Class Anthocerotae**
  Hornworts

Part 2: Vascular Plants Without Seeds

Phylum Psilophyta

Has vascular tissue (xylem and phloem); lacks roots; has scales instead of leaves; reproduces by spores (page 293)
Whiskferns

Phylum Lycophyta

Has vascular tissue; usually has creeping and erect stems; reproduces by spores (page 293)
Ground pines: *Lycopodium*

he was getting at. Every time it was spoken of elsewhere, even in church, I felt that I was missing something–something that I did not know who to ask about or even what to ask. But you helped me get it all straight, and I wanted to say thanks.''

Some Christians will take a different view than the one presented in the preceding few paragraphs. Some may feel that such matters should be covered in other circumstances. Some believe that such matters should not be discussed under any circumstances. If a person wants to condemn the teaching of human reproduction in the high school biology classroom, that is his personal privilege. That may be the prevailing sentiment and even the policy of your school. Therefore, before you plunge into a classroom presentation, it would be wise to do some checking and, with the approval of your administration, possibly present some options to parents and students.

Checking With Your Administration

Long before you come to this unit, you should meet with your administrator (and possibly others) and carefully explain your plans. Suggest the possibility of dismissing students from class if either they or their parents are uncomfortable with this material. Explain what precautions you will take to insure inoffensive, yet informative, classes. Prepare an outline of what you plan to discuss.

Attendance Options For Parents

Your administration may wish to let the parents have the option of excusing their child from class while this material is studied. Possibly at a parent-teacher fellowship or in a note, you can say the following:

> Our biology class will be covering the basics of human reproduction (on this date). We will study the structure and functions of the human reproduction system in the same way we have studied the circulatory system, the digestive system,

Phylum Sphenophyta

Has vascular tissue; thick perennial underground stem with erect annual stems; leaves in whorls from nodes on the stem; conelike spore-producing structures on top of stems (page 293)
Horsetails, scouring rushes: *Equisetum*

Phylum Pterophyta

Has vascular tissue; has roots, stems, and leaves; leaves have sori which produce spores; sexual reproduction by sperm swimming to ovum on small gametophyte plant; sporophyte plant dominant; has fiddleheads (pages 292-94)
Ferns: *Osmunda, Pteris, Polypodium*

Part 3: Vascular Plants with Seeds

A. Gymnosperms
(nonflowering plants that produce seeds not enclosed in an ovary wall)

Phylum Coniferophyta

Has vascular tissue; woody plants with needles or scalelike leaves; produces cones containing seeds (pages 295-97)
Conifers (cone-bearing plants)

Family Pinaceae Usually has needles (pages 295-96)
Pine family: pines, firs, hemlocks, cedars

Family Taxaceae Waxy, green needles; fruit looks like open-ended berries (pages 296-97)
Yew family: yews

Family Cupressaceae Usually has scales (page 296)
Cypress family: cypress, junipers, arborvitae

Family Taxodiaceae (page 297)
Redwood family: redwoods, giant sequoia, bald cypress

Phylum Cycadophyta

Has vascular tissue; often looks like a palm tree; some have fiddleheads; produces seeds in a single, large conelike structure (page 296)
Cycads, sego palms (mostly extinct)

Phylum Ginkgophyta

Has vascular tissue; has a fan-shaped leathery leaf (page 296)
Ginkgo (one living species, *Ginkgo biloba*)

B. Angiosperms
(flowering plants that produce seeds enclosed in an ovary wall)

Phylum Anthophyta

Has vascular tissue; produces flowers; seeds develop inside an ovary wall (page 297)
Angiosperms

- **Class Monocotyledoneae** Seeds have one cotyledon and one seed leaf; parallel leaf veination; roots usually fibrous; flower parts usually in threes or sixes; young stems have scattered vascular bundles and usually become hollow as they mature (page 297)
Monocots

  Family Areeidae (Palmae)
  Palm family: coconut palm, date palm, palmetto, royal palm

  Family Iridaceae
  Iris family: iris, flag

  Family Liliaceae
  Lily family: lily, onion, tulip, hyacinth, garlic, crocus

  Family Orchidaceae
  Orchid family: orchids, lady's slipper

  Family Poaceae (Graminae)
  Grass and grains family: corn, wheat, rice, grass, sugar cane, bamboo, timothy, oats, crabgrass

  Family Typhaceae
  Cattail family: common cattail

- **Class Dicotyledoneae** Seeds have two cotyledons and two seed leaves; netted leaf venation; usually has a taproot; flower

and other human systems. As has been done with all other biological topics presented, we will then discuss what the Bible has to say about the subject. We will briefly cover what the Bible tells us about the marriage relationship as well as adultery, fornication, homosexuality, and related topics. These discussions will reinforce what has already been taught at home and possibly fill a few gaps with factual information.

This subject is properly a matter of concern to parents. Parents have generally been pleased with their children's getting this factual information with a strong, Biblical basis for conduct. If you have any questions concerning what is being covered in class during this unit, or about your child's participation in it, please discuss them with me before [provide date].

Christian young people today are growing up in difficult times. The strength of a Christian education is the ability to reinforce at school the values young people learn in a good home.

If a parent comes to you concerned about what material will be presented, suggest that he read the text, and also indicate in what areas, if any, you plan to go into more detail. Of course, if he has any objections after you have clearly presented what you plan to cover in this unit (and, if necessary, why), make arrangements for his son or daughter to go somewhere else during those lessons. If the objection is not to the material but to its being covered in a classroom, the child should be required to read the textbook and take the test over the unit, a point to make clear to both the parent and the child. Certain objections by parents may require you to adjust this policy, and it may be best to check with your administration regarding this point.

Attendance Options For Students

Despite the approval of the administration and even the approval of the parents, students should not be required to attend

parts usually in fours, fives, or multiples of these numbers; young stems have vascular bundles in a ring and are usually solid (pages 297-98)
Dicots

Family Aceraceae
Maple family: maple

Family Apiaceae
Parsley family; parsley, dill, carrot, celery, Queen Anne's lace, parsnip

Family Asteraceae (Compositae)
Composite family: dandelion, sunflower, marigold, thistle, zinnia, chrysanthemum, dahlia, ragweed, sagebrush, daisy

Family Brassicaceae (Cruciferae)
Mustard family: mustard, radish, turnip, cabbage, cauliflower, sweet alyssum

Family Cactaceae
Cactus family: cactus, prickly pear

Family Caryophyllaceae
Pink family: pink, carnation, sweet William, baby's breath

Family Ericaceae
Heath family: rhododendron, azalea, heather, blueberry, cranberry, mountain laurel

Family Fabaceae
Pea family, the legume family: pea, bean, peanut, soybean, alfalfa, vetch, clover, redbud

Family Fagaceae
Beech family: beech, oak, chestnut

Family Juglandaceae
Walnut family: walnut, hickory, pecan

Family Malvaceae
Mallow family: marsh mallow, hollyhock, cotton, hibiscus

Family Nymphaeaceae
Water lily family: water lily

Family Papaveraceae
Poppy family: poppy

Family Rosaceae
Rose family: rose, apple, hawthorn, blackberry, raspberry, strawberry, pear, plum, cherry, peach, apricot, almond

Family Solanaceae
Nightshade family: potato, tomato, green pepper, tobacco, eggplant

Kingdom Animalia (Chapters 14-17)

Cellular Structure
- Cells eucaryotic
- Cells lack cell walls and plastids

Nutrition
- All heterotrophic
- Some parasitic
- Some pathogenic

Reproduction
- All reproduce sexually, but many reproduce both sexually and asexually
- All have embryonic stages, but some have both embryonic and larval stages

Motility
- Most motile with muscles
- Some sessile

classes dealing with this topic. Giving the students this option has two purposes. First, it permits you an opportunity to set the stage for the discussion of human reproduction. For success, it is crucial that the students approach this discussion with the proper attitudes. Runaway giggles can ruin the class. By warning the students ahead of time, you have a good chance of obtaining the behavior you expect. Second, there may be students who object to this material being presented. Perhaps they feel it would be so embarrassing that they could not handle it. If so, it would be good to have a conference with them; if they still do not want to attend, excuse them.

Your preliminary remarks, made several days before you come to the topic, should include the following points:

- "In a few days we will be studying the human reproductive system. Some of you already have a good knowledge of this subject, but some of you may not. We will cover the basic structures of the human reproductive systems and their biological functions in much the same way that we have discussed the various other structures of the human body. Then we will discuss what the Bible has to say about various related topics.
- "Some people become embarrassed easily when this topic is discussed. I plan to do all in my power not to embarrass anyone and not to permit anything that would be embarrassing. I will present the material in a relatively straightforward manner. The problems will come if we have some immature people in the class who just cannot handle the subject. If at the mere mention of certain organs, they glance at each other and begin giggling or in other ways act immature during our discussion, we will not be able to continue without embarrassing someone. Therefore, for these couple of days especially, I am going to ask that each of you be on your best, most mature behavior.
- "If you feel that you just cannot handle it–in other words, you will just 'die' if

Phylum Porifera

Sessile adults; supported by a system of interlacing spicules and/or spongin fibers; body bears many pores; feeding accomplished by collar cells and intracellular digestion; no respiratory or excretory structures; response to stimuli mainly on the cellular level; asexual reproduction by budding, gemmules, or regeneration; sexual reproduction by eggs and sperm; either asymmetrical or radially symmetrical (pages 342-43)
Sponges: *Grantia*

Phylum Cnidaria (Coelenterata)

Movement using a system of musclelike fibers; body consists of two cell layers forming a gastrovascular cavity with a single opening; jellylike tentacles for obtaining food; digestion is first extracellular within the gastrovascular cavity and then intracellular; no respiratory or excretory structures; nervous system consists of a nerve net with limited sensory capabilities; asexual reproduction by budding and regeneration; sexual reproduction by gametes; life cycle includes either a sessile polyp or a free-swimming stage or both; usually radially symmetrical (pages 344-46)
Cnidarians (coelenterates)

- **Class Hydrozoa** (pages 344-46)
  hydras, obelias
- **Class Scyphozoa** (pages 345-46)
  jellyfish
- **Class Anthozoa** (page 346)
  corals, sea fans

Phylum Platyhelminthes

Movement using layers of muscles; body consists of three cell layers; several organs of mesodermal origin; dorsal and ventral body surfaces flattened; some degree of cephalization; body covering of ciliated epidermis or tegument; digestion is extracellular and intracellular within an intestine that has a single opening; some adults lack digestive structures; no respiratory or circulatory organs; excretion using flame cells and a system of tubules; nervous system with nerve mass and two longitudinal nerve cords joined by transverse nerves; some have sense organs such as eyespots; asexual reproduction by division with regeneration; sexual reproduction usually by cross-fertilization between hermaphroditic adults; bilateral symmetry (pages 347-53)
Flatworms

- **Class Tuberllaria** Free-living; body covering of cilated epidermis used for motion; usually has eyespots; usually aquatic, some terrestrial (pages 347-48)
  Planarians
- **Class Trematoda** Parasitic; body covered with a tegument; adults have digestive system; adults have few sense organs (pages 349-50)
  Flukes
- **Class Cestoda** Parasitic; body covered with a tegument; adult is composed of a scolex and proglottids; lacks a digestive system; lives in host's intestines; few sense organs (pages 350, 352-53)
  Tapeworms

Phylum Nematoda

Longitudinal muscles only, permitting thrashing movements; body covering of cellular epidermis with a protective cuticle; tubular digestive system with mouth and anus; no respiratory or circulatory organs; excretion using special cells or tubules; anterior nerve ring with dorsal and ventral nerve cords; sexes are separate; bilateral symmetry (pages 350-51, 353-54)
Roundworms: trichina worm, *Ascaris,* pinworm, hookworm, whipworms

Phylum Annelida

Movement by two layers of muscles; setae for locomotion present in most; distinct external and internal segmentation; three cell layers; each layer may develop into various tissues or organs; body covered with an epidermis and moist cuticle; digestive system is complete (mouth and anus); respiration by skin or gills; closed circulatory system; excretion using paired nephridia in each body segment (except first and last few seg-

we talk about reproduction in class–we can arrange for you not to be in class at that time. If you feel that it would be wrong to talk about these things at all, speak to me in the next few days, and I will arrange for you to be absent from class on those days. I do not want to offend anyone. Some of you may want to discuss this option with your parents, especially if you feel they might object to your being present for such a discussion.

❑ ''Asking questions in class is occasionally a problem. I do not mind questions on this topic, and I will do my best to answer them. However, sometimes a question is asked or worded in an awkward way, and others in the class may be tempted to giggle. If someone asks a question, no matter how funny you may think it is, no matter what they may say about their knowledge or lack of knowledge of the subject, I will expect no laughter and no remarks. Just because someone's knowledge is lacking in an area in which yours is supposedly complete, you do not need to snicker. Very few of you will know all the material we discuss, and the test scores will show that a few of you will not know it all after we have discussed it. None of you has any room to laugh just because you happen to know something that someone else does not. Also, it is rude and immature to laugh at someone's inability to phrase a question properly.

❑ ''Do not let this discourage you from asking questions in class. If you have a question that you do not want to ask in class, you may write it out (signed or anonymous), indicate what hour you have class, put it on my desk, and I will try to incorporate the answer into the lecture. If you wish, you may ask me personally, and I will try to give you an answer.

❑ ''After the human reproductive system, we will discuss subjects such as abortion, euthanasia, adultery, fornication, homosexuality, and sexually transmitted diseases. We will study what the Bible says about them, and therefore I will ask you to bring your Bible to class on [give dates].''

ments); nervous system has anterior ganglia and a ventral nerve cord with a ganglion in each segment; asexual reproduction by regeneration in some; sexual reproduction involving hermaphroditic adults or separate sexes; bilateral symmetry (pages 355-57)
Segmented worms: earthworms, sandworms, leeches, clam worms, feather worms

Phylum Mollusca

Movement by muscular foot; body covering of ciliated epithelium; most with cephalization; has a mantle; many have a shell secreted by the mantle; digestive system is complete (mouth and anus); respiration by gills or lungs which are formed by the mantle; circulatory system with heart and colorless blood; nervous system made up of ganglia and nerve cords; many have sense organs for vision, taste, touch, smell, and balance; no asexual reproduction; sexual reproduction involving a trochophore larval stage; bilaterally symmetrical or asymmetrical (pages 358-60)
Mollusks

- **Class Bivalva (Pelecypoda)** (pages 359-60)
  Bivalves, Hatchet-footed animals: clams, oysters, scallops
- **Class Gastropoda** (pages 360-61)
  Gastropods, Stomach-footed animals: snails, slugs, nudibranches
- **Class Cephalopoda** (page 361)
  Cephalopods, Head-footed animals: squids, octopuses, nautiluses
- **Class Polyplacophora (Amphineura)**
  Chitons
- **Class Scaphopoda**
  Tooth shells

Phylum Echinodermata

Locomotion by a water-vascular system and tube feet; supported by a system of hardened plates beneath the epidermis; digestive system complete (mouth and anus); respiration usually by skin-gills; no well-organized circulatory or excretory organs; asexual reproduction by regeneration; sexual reproduction involving separate sexes and external fertilization; life cycle involves free-swimming larval stage; salt water; radial symmetry in adults, bilateral symmetry in larvas (pages 362-63)
Echinoderms, spiny-skinned animals

- **Class Stelleroidea** (pages 362-63)
  starfish, brittle stars
- **Class Echinoidea** (page 363)
  sea urchins, sand dollars
- **Class Holothuroidea** (page 363)
  sea cucumbers
- **Class Crinoidea** (page 363)
  sea lilies

Phylum Arthropoda[10]

Movement by jointed appendages moved by muscles; body segmented, usually with head, thorax, and abdomen; sometimes body segments are fused; body covered by exoskeleton containing chitin; exoskeleton secreted by epidermis and periodically molted; digestive system complete (mouth and anus); circulatory system open, with a dorsal heart; respiration by gills, tracheae, and book lungs; excretion by green glands or Malpighian tubules; nervous system with anterior ganglia and ventral nerve cord with ganglia; sense organs include antennas, sensory hairs, compound and/or simple eyes; sexes usually separate; parthenogenesis in some (Chapter 15)
Arthropods, joint-footed animals

- **Class Malacostraca (Crustaceae)** Cephalothorax and abdomen; two pairs of antennas; one pair mandibles, two pairs maxillae and one to three pairs of maxillipeds (mouthparts); one pair of legs or less per body segment; respiration by gills; usually has larval stages; usually aquatic, few terrestrial (pages 366-68)
  Malacostracans (crustaceans): crayfish, crabs, barnacles, shrimp, lobsters, pill bugs
- **Class Arachnida** Cephalothorax and abdomen; no antennas; chelicerae and pedipalps (mouthparts); four pairs of walking legs attached to thorax; respiration by book

If you excuse a student from class during this discussion on reproduction, you may wish to make comments to the class to discourage peer intimidation. However, this is not often necessary.

lungs or tracheae; no larval stages (except for ticks); usually terrestrial (pages 369-73)
Arachnids: spiders, ticks, mites, scorpions

- **Class Chilopoda** Head and many body segments; one pair of antennas; one pair of mandibles and one or two pairs of maxillae (mouthparts); has poison glands; carnivorous; one pair of walking legs per body segment; respiration by tracheae; no larval stages; terrestrial (page 372)
Centipedes

- **Class Diplopoda** Head, short thorax, and many body segments; one pair of antennas; one pair mandibles and one pair maxillae (mouthparts); eats dead plant material; two pairs of walking legs per body segment; respiration by tracheae; no larval stages; terrestrial (page 372)
Millipedes

- **Class Insecta**[11] Head, thorax, and abdomen; one pair of antennas; one pair mandibles, one pair maxillae, one labium, one labrum (mouthparts); three pairs of legs on thorax; may have one or two pairs of wings on thorax; respiration by tracheae; usually has larval stages; mainly terrestrial (Chapter 15B)
Insects

  - **Order Coleoptera** (sheath wing) Complete metamorphosis (larva called a grub); one pair horny wings covering a pair of membranous wings; chewing mouthparts (page 386)
  Beetles, weevils: Japanese beetle, lady bugs, rice weevils, blister beetles, cotton boll weevil

  - **Order Diptera** (two wings) Complete metamorphosis (larva called a maggot); one pair of membranous wings; piercing or sponging mouthparts (page 386)
  Flies, mosquitoes, gnats

  - **Order Hymenoptera** (membranous wing) Complete metamorphosis; two pairs of membranous wings; chewing or siphoning mouthparts; many have stinger in last abdominal segment; many are social insects, forming colonies (pages 380-82)
  Ants, bees, wasps

  - **Order Lepidoptera** (scale wing) Complete metamorphosis (larva called a caterpillar and has chewing mouthparts); two pairs of scale-covered wings; adults have siphoning mouthparts (pages 382, 386)
  Butterflies, moths, skippers

  - **Order Orthoptera** (straight wing) Incomplete metamorphosis on land; one pair of membranous and one pair of leatherlike wings; chewing mouthparts (page 387)
  Grasshoppers, crickets, cockroaches, mantids

  - **Order Anoplura** (unarmed tail) No metamorphosis; no wings; piercing and sucking mouthparts
  Sucking lice

  - **Order Thysanura** (tassel tail) No metamorphosis; no wings, chewing mouthparts
  Silverfish, firebrats

  - **Order Dermaptera** (skin wing) Incomplete metamorphosis on land; one pair of leatherlike wings; chewing mouthparts
  Earwigs

  - **Order Hemiptera** (half wing) Incomplete metamorphosis on land; forewings have a leatherlike anterior half and a posterior membranous half; hind wings are membranous; many lack wings and sucking mouthparts
  True bugs: bedbugs, stinkbugs, water bugs, water striders, chinch bugs

  - **Order Homoptera** (same wing) Incomplete metamorphosis on land; two pairs of membranous wings; piercing and sucking mouthparts
  Cicadas, aphids, leaf-hoppers, scale insects

  - **Order Isoptera** (equal wing) Incomplete metamorphosis on land; two pairs of membranous wings shed at maturity;

Answers–Thought Questions 14C *(p. 358)*
(continued from p. 357)

3. **(a)** The sponge is generally unresponsive. The hydra has a nerve net that enables the entire body to respond to a single stimulus. The planarian possesses an elaborate nervous system and responds to light, taste, smell, and touch. The tapeworm has sense organs in only the scolex. The *Ascaris* has a ring of nerve tissue around the pharynx and two long nerve cords extending down its sides; it responds to touch and some chemicals. The earthworm has a "brain" composed of two ganglia, which are connected to other ganglia by the ventral nerve cord. **(b)** In the sponge, amebocytes transport nutrients throughout the body. In the hydra, food circulates in the gastrovascular cavity. In the planarian, digested food diffuses from the intestine throughout the body. In the *Ascaris*, digested food from the intestines diffuses into the body fluids and circulates as the worm moves. In the earthworm, a closed circulatory system composed of "hearts" and blood vessels absorbs and distributes nutrients and oxygen. **(c)** The planarian may regenerate, the hydra buds and regenerates, and certain species of earthworms sometimes regenerate. The tapeworm forms proglottids posterior to the scolex. The *Ascaris* has no asexual forms of reproduction. **(d)** In hydras, the free-swimming sperm fertilize the egg, which is attached to another hydra; the zygote develops into an embryo, which breaks away from the parent and becomes a new hydra. Planarians reproduce sexually by cross-fertilization. Each proglottid of a tapeworm contains testes and ovaries; the fertilized eggs remain in the proglottid until it is egested with feces, when they are released into the environment. After the male and female *Ascaris* worms

chewing mouthparts
Termites

- **Order Ephemeroptera** (lasting-only-a-day wing) Incomplete metamorphosis in water; two pairs of membranous wings; adults do not feed
Mayflies
- **Order Odonata** (toothed) Incomplete metamorphosis in water; two pairs of membranous wings; chewing mouthparts
Dragonflies, damselflies
- **Order Neuroptera** (nerve wing) Complete metamorphosis; two pairs of membranous wings; chewing mouthparts
Dobsonflies, ant lions, lacewings
- **Order Siphonaptera** (siphon, without wings) Complete metamorphosis; no wings; sucking mouthparts
Fleas

- **Class Merostomata**
Horseshoe crabs

Phylum Acanthocephala
Spiny-headed worms

Phylum Brachiopoda
Brachiopods, lampshells

Phylym Ectorprocta (Bryozoa)
Bryozoans (sea mosses)

Phylum Chaetognatha
Arrow worms

Phylum Ctenophora
Comb jellies

Phylum Nematomorpha
Horsehair worms

Phylum Nemertea
Proboscis worms, ribbon worms

Phylum Phoronidea
Phoronis

Phylum Rotifera (Trochelminthes)
Rotifers

Phylum Chordata
Has a dorsal notochord which is replaced by vertebrae in many; has dorsal tubular nerve cord; has pharyngeal pouches during embryonic development (Chapters 16 and 17)
Cordates

Subphylum Cephalochordata
Retains notochord throughout life (page 389)
Amphioxuses

Subphylum Urochordata
Notochord as larva only (page 389)
Tunicates or sea squirts

Subphylum Vertebrata
Internal vertebral column supports body; usually two pairs of limbs (pelvic and pectoral); skeleton of cartilage and/or bone; body divided into head, trunk, and usually a neck and tail; closed circulatory system; muscular heart is ventral to vertebral column and has two, three, or four chambers; red blood cells contain hemoglobin; digestive system complete with an alimentary canal composed of esophagus, stomach, and intestines located ventral to vertebral column; liver and pancreas attached to alimentary canal; brain consisting of several lobes; nerve cord (spinal cord) dorsal to vertebral column; most have projections from vertebrae surrounding and protecting the nerve cord; most have eyes, ears, and nostrils on head; paired cranial nerves branch from brain and serve major sensory organs of the head, and they affect many body movements and functions; paired spinal nerves branch from spinal cord and serve sensory organs of the trunk and appendages, and they affect many body movements and functions; kidneys filter wastes from blood; sexes usually sep-

mate, the female deposits up to 200,000 eggs per day; these are egested with the feces of the host and must be swallowed by another host if the worm embryos are to survive. Earthworms cross-fertilize and deposit eggs in a cocoon, from which the young worms emerge and burrow into the soil.

arate, each individual usually having a pair of either ovaries or testes (pages 389-93)
Vertebrates

- **Class Agnatha**[12] Scaleless body; no jaws; circular, sucking mouth; no stomach; skeleton of cartilage; unpaired fins; respiration by gills (no operculua); two-chambered heart; ectothermic; external fertilization; oviparous development (page 395)
  Jawless fish: lampreys, hagfish

- **Class Chondrichthyes** Skin with mucus-producing glands and placoid scales; mouth usually on ventral surface; jaws with teeth; skeleton of cartilage; fins both paired and unpaired; respiration by gills; two-chambered heart; ectothermic; fertilization generally internal; development usually ovoviviparous or viviparous (pages 398-99)
  Cartilaginous fish: sharks, rays, skates

- **Class Osteichthyes (Pisces)** Skin with many mucus-producing glands; usually covered by scales; mouth with jaw located in the front of the head; skeleton chiefly of bone with some cartilaginous parts; fins both paired and unpaired; respiration by gills covered with opercula, two-chambered heart; often an air bladder for controlling depth in water; ectothermic; fertilization generally external; development usually oviparous, but some ovoviviparous and viviparous; eggs usually minute and numerous (pages 394-403)
  Bony fish: perch, eels, salmon, coelacanth, guppy

- **Class Amphibia** Skin smooth with many glands and chromatophores (pigment cells); no scales; large mouth; nostrils open into mouth cavity; skeleton chiefly of bone; two pairs of limbs usually present (some lack limbs); no claws, feet often webbed; respiration by gills, lungs, mouth lining, and skin–either individually or in combination; three-chambered heart as adult, two-chambered heart in larva; ectothermic; fertilization generally external (except salamanders); development usually oviparous; eggs surrounded by jellylike coat (Chapter 16C)
  Amphibians

  - **Order Apoda** Legless (pages 406-7)
    Caecilians
  - **Order Caudata** Has head, trunk, and tails; most have two pairs of identical legs; internal fertilization (page 407)
    Salamanders: tiger salamanders, newts
  - **Order Anura** Wide head fused with short body; no tail; front pair of legs short; hind pair of legs long with webbed toes (pages 406-7)
    Frogs, toads

    Genus *Rana* (page 406)
    Common frogs: leopard frog *(R. pipiens)*, bullfrog *(R. catesheiana)*, green frog *(R. clamitans)*, pickerel frog *(R. palustris)*

    Genus *Bufo* Has poison glands behind tympanic membrane (page 406)
    Common toads: American toad *(B. americanus)*, oak toad *(B. quercicus)*, giant toad *(B. marinus)*

    Genus *Hyla* Has sticky pads on enlarged toes (page 406)
    Tree frogs: spring peeper *(H. crucifer)*, green tree frog *(H. cinerea)*

- **Class Reptilia** Body covering of tough, dry scales; limbs, if present, paired; clawed toes; respiration by lungs; most have three-chambered heart with partial division of ventricle, but some have four-chambered heart; predominantly ectothermic; fertilization internal; oviparous, producing amniotic eggs with a leathery shell; some ovoviviparous (Chapter 16D)
  Reptiles

  - **Order Rhynchocephalia** (page 417)
    Tuataras (one living species: *Sphenodon*)
  - **Order Squamata** Sheds scales; jaws have teeth; detached quadrate bone (pages 417-21)
    Snakes, lizards

    Suborder Serpentes No limbs; no eyelids; no ear openings (pages 417-20)
    Snakes

Suborder Sauria Two pairs of limbs; movable eyelids; ear openings (pages 420-21)
Lizards

- **Order Testudinata** Has an upper and lower shell of fused bones and scales; jaws with no teeth (page 421)
Turtles, tortoises

- **Order Crocodylia** Has a four-chambered heart; scales grow and are not molted (pages 421-22)
Alligators, crocodiles, caimans

❑ **Class Aves** Body covering of feathers; body spindle-shaped with head, neck, trunk, and tail; neck usually long and flexible; skeleton composed of porous, lightweight bones; forelimbs (wings) used for flight in most species; lower section of hind limbs usually covered with scales; body supported on hind limbs only; toothless bill; four-chambered heart; respiratory system with air sacs; endothermic; excretory system usually lacks bladder; oviparous reproduction with egg enclosed in lime-containing shell; female with only one developed ovary and oviduct (Chapter 17A)
Birds

- **Order Sphenisciformes** Flightless birds that swim (page 430)
Penguins

- **Order Struthioniformes** Flightless birds that run (page 430)
Ostriches, rheas, emus

- **Order Falconiformes** Birds of prey; daytime hunters (pages 430-31)
Falcons, eagles, hawks, vultures

- **Order Stringiformes** Birds of prey; nighttime hunters (pages 430-31)
Owls

- **Order Galliforme** Game birds (pages 431-32)
Quails, pheasants, ptarmigans, partridges, turkeys

- **Order Columbiformes** Game birds (pages 431-32)
Pigeons, doves

- **Order Anseriformes** Waterbirds that swim (page 432)
Ducks, swans, geese

- **Order Pelecaniformes** Waterbirds that dive (page 432)
Pelicans, gannets, cormorants

- **Order Ciconiiformes** Waterbirds that wade (page 432)
Herons, bitterns, storks, flamingos

- **Order Passeriformes** Songbirds (page 432)
Skylarks, nightingales, finches, mockingbirds, swallows, crows, ravens, cardinals, robins

- **Order Apodiformes**
Hummingbirds

- **Order Caprimulgiformes**
Whippoorwills

- **Order Charadriiformes**
Gulls, sandpipers, terns

- **Order Coraciiformes**
Cuckoos, roadrunners

- **Order Piciformes**
Woodpeckers, flickers, toucans

- **Order Psittaciformes**
Parrots, parakeets

❑ **Class Mammalia** Body covering of hair; usually has teeth in both jaws; two pairs of limbs (one pair in some) designed for running, climbing, digging, grasping, or flying; respiration by lungs; diaphragm used to assist in breathing; four-chambered heart; endothermic; reproduction viviparous with young sustained within mother by a placenta (all except Monotremata and Marsupialia); some ovoviviparous (Monotremata); some lack placenta (Marsupialia); young nourished by milk from mammary glands (Chapter 17B)
Mammals

- **Order Monotremata** Lays eggs in leathery shell; lacks nipples (page 442)
  Egg-laying mammals: duckbilled platypuses, spiny anteaters
- **Order Marsupialia** No placenta; young born immature and develop in an abdominal pouch where nipples are located (pages 444-45)
  Pouched mammals: kangaroos, koalas, opossums
- **Order Rodentia** Two sets of chisel-shaped incisors (teeth) which continue to grow throughout the animal's life; generally herbivores (pages 442-43)
  Gnawing mammals: rats, squirrels, mice, porcupines, beavers, hamsters, jerboas, water voles
- **Order Carnivora** Large, pointed canine teeth for ripping and tearing meat (some omnivores); short digestive system (pages 443-46)
  Meat-eating mammals: lions, tigers, bears, dogs, weasels, seals, raccoons, wolves, coyotes
- **Order Cetacea** Born and lives entire life in the water; pectoral limbs usually flippers; pelvic limbs often a "tail flipper"; echolocation for underwater guidance (page 447)
  Marine mammals: whales, dolphins, porpoise, sea lions
- **Order Primates** Limbs permit erect (or nearly erect) walking; five fingers or toes, with most having nails (not claws); eyes face front; often has social heirarchy; has incisors, canines, and molars (omnivores) (pages 447-48)
  Erect mammals

  Family Callitrichidae
  Marmosettes, tamarins

  Family Cebidae Tail used for climbing (prehensile)
  New world monkeys: spider monkeys, squirrel monkeys, howler monkeys

  Family Cercopithecidae Tail which is not used for climbing (nonprehensile)
  Old world monkeys: baboons, rhesus monkeys, mandrills

  Family Hylobatidae Forelimbs twice as long as hind limbs; tree dwellers
  Lesser apes: siamangs, gibbons

  Family Lemuridae
  Lemurs

  Family Pongidae No tail; long hindlimbs; lives in trees and on land
  Great apes: gorillas, chimpanzees, orangutans
- **Order Perissodactyla** Legs have either a single toe with a curved hoof or three toes, each with a hoof; herbivores (pages 448-52)
  Odd-toed hoofed mammals: horses, zebras, rhinoceroses
- **Order Artiodactyla** Stands on two or four toes each with a hoof; herbivores with long digestive systems (pages 448-52)
  Even-toed hoofed mammals

  Suborder Ruminantia Has rumens (chews the cud)
  Ruminants

  Family Bovidae Many have horns (pages 449-50, 452).
  Bovines: cattle, sheep, goats, antelopes

  Family Cervidae Most have antlers.
  Deer, elk, reindeer, wapiti

  Family Giraffidae
  Giraffes, okapi

  Suborder Suina Lacks rumens
  Swine (pigs), hippopotamuses, peccaries

  Suborder Tylopoda Has rumens; four toes
  Camels, llama
- **Order Chiroptera** Forelimbs are wings; most nocturnal; many sense objects by echolocation
  Flying mammals: bats
- **Order Insectivora** Lives under ground; eats small invertebrates
  Insect-eating mammals: shrews, hedgehogs, moles

- **Order Edentata** Small or no teeth
  Toothless mammals: sloths, anteaters, armadillos
- **Order Lagomorpha** Has chisel-shaped front teeth; hind limbs used for running and jumping
  Rodentlike mammals: rabbits, hares, pikas
- **Order Proboscidea** Large herbivores; flexible trunks
  Trunked mammals: elephants, tapirs
- **Order Sirenia** Aquatic; front limbs as flippers; hind limbs usually absent
  Aquatic mammals: sea cows, manatees

Footnotes

1. At one time the kingdom Monera was divided into two phyla: Schizomycophyta (Schizophyta)–containing all bacteria, mycoplasmas, rickettsias, and spirochetes (none of which contained true chlorophyll)–and Cyanophyta–containing the blue green algae (which do contain true chlorophyll).
2. Some classification systems have a third subkingdom, "the fungal protists," which includes the slime molds and similar organisms.
3. Some classification systems use phylum Sarcomastigophora which contains subphyla Sarcodina and Mastigophora.
4. Some classification systems divide phylum Sporozoa into several phyla: Apicomplexa, Microspora, Ascetospora, Myxozoa.
5. Some classifications place phyla Chlorophyta, Phaeophyta, and Rhodophyta in the kingdom Plantae.
6. Some classification systems list phylum Eumycophyta which contains class Phycomycetes (Zygomycota and Oomycota), class Ascomycetes (the sac fungi of phylum Ascomycota), class Deuteromycetes (the imperfect fungi of phylum Ascomycota), and class Basidiomycetes (Basidiomycota).
7. The imperfect fungi, those that lack a known form of sexual reproduction, are placed in phylum Ascomycota, awaiting observation of the sexual reproduction many scientists believe they have.
8. In some classification systems Myxomycota, Oomycota, and Acrasiomycota are placed in the Kingdom Protista.
9. An older classification system for the Kingdom Plantae:
   - Phylym Bryophyta
   - Phylum Tracheophyta
     - Subphylum Psilosida
     - Subphylum Lycopsida
     - Subphylum Sphenopdisa
     - Subphylum Pteropsida
       - Class Filicineae (ferns)
       - Class Gymnospermae
       - Class Angiospermae
         - Subclass Monocotyledoneae
         - Subclass Dicotyledoneae
10. The phylum Arthropoda can be divided into subphyla Crustacea (class Malacostraca), Chelicerata (classes Arachnida and Merostomiata), and Uniramia (classes Diplopoda, Chilopoda, and Insecta).
11. The first five orders in the class Insecta are the ones discussed in the textbook in alphabetical order. The next orders are listed in the following groups, alphabetically within the group: those with no metamorphosis, those with incomplete metamorphosis on land, those with incomplete metamorphosis in water, and those with complete metamorphosis. These are the fifteen most common of the twenty-six insect orders.
12. Some classification systems make Agnatha into a superclass containing Class Cephalaspidomorphi (the lampreys) and Class Myxini (the hagfish) .

Appendix C

Metric System Conversion Table

Metric Unit	Appropriate English System Equivalent	Metric Conversion	Handy Comparisons
Length			
kilometer (km)	1090 yards	1000 m	11 football fields
meter (m)	1 yard 3 inches; 39 inches	0.001 km	a yardstick and 3 inches
centimeter (cm)	0.4 inch	0.01 m; 10 mm	a nickel is about 2 cm in diameter
millimeter (mm)	0.04 inch	0.1 cm	the thickness of a penny
micrometer (µm)	0.00004 inch	0.001 mm	a red blood cell is 7.5 micrometers
nanometer (nm)	0.00000004 inch	0.001 µm	a polio virus is 25 nanometers
Angstrom (Å)	0.000000004 inch	0.1 nm	1/2 size of a hydrogen atom
Weight			
kilogram (kg)	2.2 pounds; 35 ounces	1000 g	2/3 the weight of this book
gram (g)	0.035 ounce	0.001 kg	the weight of 24 drops of water; a dime weighs 2.3 g
milligram (mg)	0.000035 ounce	0.001 g	the weight of 0.2 of a drop of water
Volume			
liter (L)	1 quart and 1/4 cup	1000 ml	1/4 gallon
milliliter (ml)	0.004 cup; 1000 µl	0.001 L	the volume of 24 drops of water, about 1/5 teaspoon
microliter (µl)	0.000004 cup	0.001 ml	the volume of 0.024 of a drop of water
liter dry (L)	0.03 bushel		the volume of about one quart

Temperature

On the Celsius (centigrade) scale 0° is the freezing point of water, and 100° is the boiling point of water at sea level. On the Fahrenheit scale, 32° is the freezing point of water, and 212° is the boiling point of water at sea level. Normal body temperature is 37°C or 98.6°F.

The following formulas can be used to convert one to another:

- °F to °C: subtract 32, multiply by 5, divide by 9.
- °C to °F: multiply by 9, divide by 5, add 32.

Unit Abbreviations

Å Angstrom(s)
A.D. anno Domini (after the death of Christ)
B.C. before the birth of Christ
bpa bushels per acre
bpm beats per minute
bps beats per second
bu. bushel(s)
C Celsius
Cal kilocalorie(s)
cm centimeter(s)
F Fahrenheit
g gram(s)
gal. gallon(s)
gm gram(s)
in. inches
kcal kilocalorie(s)
kg kilogram(s)
km milometer(s)
kmph kilometer(s) per hour
L or l liter(s)
lb. pound(s)
m meter(s)
mg milligram(s)
mi. mile(s)
ml milliliter(s)
mm millimeter(s)
mm Hg millimeters of mercury
μl microliter(s)
μm micrometer(s)
nm nanometer(s)
oz. ounce(s)
pH acidity scale (see pages 47-49)
pt. pint(s)
qt. quart(s)
sec. second(s)
sq. m. square meter(s)
sq. mi. square mile(s)
sq. yd. square yard(s)
wk. week(s)
X times larger, power (enlargement)
yd. yard(s)
yr. year(s)

abdomen A body region posterior to the thorax.
abscisic acid A plant hormone that stimulates the formation of the abscission layer.
abscission layer A layer of cells at the base of leaf petioles and fruits which die, causing the separation of the leaf or fruit from the stem.
absorption The movement of food molecules from the alimentary canal into the bloodstream.
accommodation The ability of the eye to focus on objects at different distances.
acetyl coA (acetyl coenzyme A) A two-carbon substance found in many cellular metabolisms.
acid Any substance that yields hydrogen ions when dissolved in water; a substance that neutralizes a base.
Acquired Immune Deficiency Syndrome (AIDS) A viral disease which affects the human immune system.
activation energy The initial energy necessary to start a reaction.
active absorption The process of taking water into root epidermal cells; the result of differences in ion concentration.
active site The area of an enzyme that combines with the substrate.
active transport The movement of molecules across cellular membranes against the concentration gradient; requires cellular energy expenditure.
adaptation According to evolutionists, the change of an organism that enables it to survive in a new environment.
addiction The continued use of habit-forming drugs; the inability to stop using a drug for physical or psychological reasons or both.
adenosine diphosphate (ADP) The molecule that is produced when ATP is split to yield energy.
adenosine triphosphate (ATP) A compound that serves as a temporary energy storage molecule in all cells.
ADP (See **adenosine diphosphate.)**
adrenal cortex The larger outer region of the adrenal glands; secretes the sex hormones, mineralcorticoids, and glucocorticoids.
adrenal glands Endocrine glands located on each kidney; composed of cortex and medulla regions.
adultery The act of sexual relations between a married person and anyone other than that person's marriage partner.
adventitious roots Roots that grow from a stem, petiole, or leaf.
aerial hyphae Hyphae of a fungus that grow above the substrate.
aerobe, obligate An organism that can live only in the presence of free oxygen.
aerobic Processes that require oxygen.
aerobic cellular respiration The oxygen-requiring process of breaking down a food substance to obtain cellular energy.
agar A gelatinous substance obtained from red algae; used as a culture medium in microbiology.
agglutinate The clumping together of blood cells that occurs when blood types are not matched properly in a transfusion.
AIDS (See **Acquired Immune Deficiency Syndrome.)**
air bladders Structures in algae and many fish that enable them to float.
albinism A genetic abnormality resulting in a lack of pigmentation.
albumen The white of an egg.
albumins Blood proteins that are primarily responsible for maintaining the blood volume.
alcoholic fermentation The formation of alcohol and carbon dioxide from glucose; performed by yeast cells.
algin A purified carbohydrate obtained from brown algae.
alimentary canal A group of digestive organs arranged in a continuous tube extending from mouth to anus.
allantois An embryonic membrane in an amniote egg that serves for respiration and excretion for the embryo; in humans, becomes part of the umbilical cord.
alleles A pair of genes that has the same position on homologous chromosomes.
allergy A disorder caused by the body's producing antibodies when stimulated by natural, nonpathogenic substances.
alternation of generations The reproductive cycle in which the asexual reproductive stages give rise to sexual reproductive stages that, in turn, give rise to asexual reproductive stages.
atricial chicks Birds that are immature and helpless when hatched.
alveoli (sing., alveolus) Small bubblelike structures of the lung where gases are exchanged between the atmospheric air and the blood.
amebocytes Amebalike cells in a sponge's mesenchyme that produce spicules, transport food, and eliminate waste.
ameboid movement A constant change in shape by an ameba or similar cell by the formation of pseudopodia.
amensalism The situation in which one population in an environment is inhibited by another, while the other is not affected by the first.
amino acid The basic "building block" of a protein molecule.
amniotic egg An egg that has a leathery or hard shell in which the embryo is enclosed by an amnion.
amplexus The physical contact of a male and a female amphibian that stimulates the female to release eggs into the water.
amylase An enzyme secreted by the salivary glands and pancreas to digest starches into sugars.
anabolism The phase of metabolism that builds molecules and stores energy; the constructive part of metabolism.
anaerobe, obligate An organism that cannot live in the presence of free oxygen.
anaerobic Processes that do not require oxygen.
anatomical position A standing position of the human body with the arms at the sides and the palms turned forward.
anatomy The science that deals with the structure of organisms.
androgens Male sex hormones produced by the testes.
aneuploid An organism in which the chromosome number is not an exact multiple of the haploid number.
annual plant A plant that grows from a seed, produces more seeds, and dies during one growing season or within one year.
annual ring In woody stems, one layer of xylem that forms during one year.
ANS (See **autonomic nervous system.)**
antagonist The muscle that performs an action opposite to that of the muscle acting as the prime mover.
antediluvian Before the Flood.
antenna (pl., **antennas**) Elongated, movable sensory appendage on the head of various invertebrates.
antennules Sensory appendages responsible for the sense of balance in some arthropods.
anther The structure on a stamen in which pollen is produced.
antheridium (pl., **antheridia**) The reproductive structure that produces sperm in certain plants.
anthropology The study of the origin, races, and cultural development of man.
antibiotics Chemicals, produced by living organisms, that naturally kill or inhibit the growth of other organisms.
antibodies Protein substances produced to eliminate antigens that have entered the body.
anticodon The triplet of nucleotides on transfer RNA that will pair with the codon of the messenger RNA to line up amino acids during protein synthesis.
antigens Foreign materials in the body that stimulate antibody production or begin cell-mediated immunity.
anus The posterior opening of the alimentary canal for egestion of feces.
apical dominance A condition in plants in which the terminal bud suppresses the growth of lateral buds.
apparent age A feature of God's creation; man, plants, and animals created in their mature forms; earth created with the appearance of age.
applied science Using pure science to solve practical problems.
aquaculture The farming of aquatic environments.
aqueous humor A transparent, watery fluid in the eyeball that nourishes the cornea.

arachnoid membrane A thin membrane surrounding the brain and spinal cord; between the dura mater and pia mater.
archegonium (pl., **archegonia**) Female reproductive structure in algae, fungi, and some plants.
artery Any blood vessel that carries blood away from the heart.
articular cartilage A cartilage layer covering the epiphyses of bones; provides cushioning and smooth movement at the joints.
artificial insemination The mechanical placement of a male's sperm into a female's reproductive organs.
ascus The structure in which the haploid ascospores are formed in the molds of the class Ascomycota.
asexual reproduction Producing a new organism without the fusion of a sperm and an ovum.
assimilation The conversion of nutrients into living cells; a process of growth.
aster A collection of microtubules radiating from the centriole; some of these microtubles form the spindle during cell division.
astigmatism A condition in which the cornea or lens or both are unequally curved and the light rays from an object are not equally focused on the retina.
asymmetrical In organisms, those whose body parts are unlike in size, shape, or structure and cannot be divided into like halves.
atom The smallest unit of an element that can exist either alone or in combination.
ATP (See **adenosine triphosphate.**)
atrioventricular node (AV node) A mass of specialized cardiac tissue located in the right atrium; responsible for the contraction of the ventricles.
atrioventricular valve One of the membranous structures between the atria and ventricles in the heart that prevent backflow of blood into the atria.
atrium (pl., **atria**) One of the heart chambers that receives blood from different parts of the body.
auricle An outer flap of ear tissue leading to the auditory canal.
autonomic nervous system (ANS) The involuntary portion of the peripheral nervous system.
autophagy A process whereby a cell forms a membrane around some of its own cellular parts and digests them.
autosomes Any chromosome other than a sex (X or Y) chromosome.
autotrophs Organisms that are able to make their own food.
auxin A growth-regulating hormone in plants.
avascular Human and animal tissues in which there are no blood vessels.
AV node (See **atrioventricular node.**)
axial skeleton The portion of the skeleton that supports and protects the organs of the head, neck, and trunk.
axon The portion of a neuron that carries impulses away from the cell body.

bacillus (pl., **bacilli**) A rod-shaped bacterium.
bactericidal Capable of killing bacteria.
bacteriophage A virus that parasitizes a bacterial cell.
bacteriostatic Preventing the multiplication of bacteria.
basal body The action-controlling structure at the base of a cilium or flagellum.
basal disc The flattened structure at the lower end of certain cnidarians; used for attaching to objects and for locomotion.
basal metabolic rate (BMR) The amount of calories needed to maintain normal body functions while at rest.
base A substance that releases hydroxyl ions when dissolved in water; neutralizes an acid.
basidia (sing., **basidium**) The microscopic structures in Basidiomycota that produce the asexual basidiospores.
B cells Cells involved in humoral immunity.
benign tumor A tumor characterized by localized growth.
Biblical kind The natural groupings of organisms established by God.
biennial plant A plant that sprouts and grows in one season but does not flower and produce seeds until the following growing season.
bile A greenish fluid produced by the liver; necessary for the breakdown and absorption of fatty substances.
binomial nomenclature A system of naming organisms in which each organism is given a genus and species name.
biodegradable Capable of being broken down by the environment and returned to the normal cycling of substances.
biogenesis The concept that life comes only from pre-existing life.
biological father The man who supplies the sperm for the zygote of a child.
biological key An arrangement of descriptions and illustrations used to identify an organism.
biological magnification The process that concentrates small quantities of a substance into larger quantities as it is passed in a food chain.
biological mother The woman who supplies the ovum for the zygote of a child.
biological rhythm (biological clock) Periodic recurring changes in organisms; the mechanism that causes organisms to change regularly either their location or activities or both.
biology The science that deals with living organisms and vital life processes.
biome A major biotic community with populations of climax species.
biopsy The removal of a sample of a tissue to be observed for abnormalities.
biosphere The part of the world in which life can exist.
biosynthesis The formation of a chemical compound by a living organism.
biotic community All the living things (populations) in an ecosystem.
birth canal The cervix and vagina; very elastic at time of delivery to allow passage of the baby.
blastocyst A fluid-filled sphere of embryonic cells.
blood plasma The liquid portion of the blood.
blood pressure The pressure of the blood against the walls of arteries caused by contraction of the heart ventricles.
bloom (bloom condition) A rapid, seasonal reproduction of a particular organism in an optimal environment.
BMR (See **basal metabolic rate.**)
body tube The cylindrical part of the microscope between the eyepiece and the objectives.
bone marrow, red A tissue that makes red blood cells and that is located in the marrow cavities of some bones.
bone marrow, yellow Fatty tissue that gradually replaces red bone marrow as humans become older.
Bowman's capsule The end of the nephrons of the kidney where blood plasma is absorbed from the blood vessels.
bracts Brightly colored leaves on plants that appear to be showy flowers; leaflike structures.
breech birth A delivery in which the baby is positioned with his posterior end toward the birth canal.
bronchi (sing., **bronchus;** adj., **bronchial**) The two branches of the trachea which carry air to the lungs; the bronchial tubes.
Brownian movement The movement of molecules caused by the heat they possess.
budding A type of asexual reproduction in which portions from the parent form a new individual; in plants, a method of grafting in which a bud is placed under the bark of another plant.
buffer A dissolved substance which makes a solution resistant to a change in its pH (the concentration of hydrogen ions).
bulk feeder An organism which eats either all or major portions of its prey.
bundle of His The specialized heart muscle tissue which transports impulses from the AV node in the heart to each ventricle.
bursas (sing., **bursa**) Saclike structures between tendons, ligaments, and bones that cushion and reduce friction.

calcitonin A thyroid hormone that lowers the blood calcium level.
calorie A measurement of heat produced during oxidation of food.
calyx The collective name for all the sepals of a flower.
canines Pointed teeth generally used for tearing; members of the dog family.
canker An open sore or lesion producing a fluid discharge.
canopy theory The theory that states that a canopy of water vapor surrounded the earth during the time before the Flood.

capillaries Blood vessels that have walls one cell thick where diffusion of nutrients and exchange of gases occur.
capillarity The property of water that causes it to cling to surfaces.
capsule A cellular secretion surrounding certain algae and bacteria.
carapace The portion of the exoskeleton that covers the cephalothorax in some arthropods; dorsal part of a tortoise's body shell.
carbohydrates Organic compounds that contain only carbon, hydrogen, and oxygen.
carcinogens Cancer-causing substances.
cardiac cycle The series of physical events that transports blood through all four heart chambers during one heartbeat.
carnivorous animals Animals that eat other animals.
carrier A heterozygous organism that is normal for a trait but which also has a recessive gene for an undesirable trait and can transmit that gene to offspring.
cartilage A flexible connective tissue found in the nose, outer ear, between ribs and sternum, and on the ends of long bones.
catabolism The phase of metabolism which breaks down a molecule or releases energy; the destructive phase of metabolism.
catalyst A substance that affects the rate of a reaction but is not changed in the reaction.
cataract An opaqueness of the lens of the eye.
catkins Male flowers found in some plants.
cecum A blind pouch which forms the first portion of the large intestine; its lower end forms the appendix.
cell The unit of function and structure of life.
cell body The part of the neuron with the greatest diameter; contains the nucleus.
cell-mediated immunity An immunity to disease involving activated cells.
cell membrane (plasma membrane) The outermost boundary of a cell.
cell specialization Genetically identical cells developing differently to become the various structures of the adult organism.
cell theory The theory that all living organisms are made up of microscopic units called cells.
cellular membrane The structures made of lipids and proteins which form thin membranes around and in cells.
cellular respiration The breakdown of foods (glucose) to release energy including both aerobic and anaerobic cellular respiration.
cellulose Chains of glucose molecules; found in plant cell walls.
cell wall A rigid structure manufactured by the cell; located outside the plasma membrane; often made of cellulose, silica, or other substances.
cementum An external bony layer on the roots and the neck of a tooth; it anchors the tooth in the socket.
central nervous system The part of the nervous system consisting of the brain and spinal cord.
centrioles Organelles composed of microtubules and located near the nucleus; doubles before cell division to establish the poles.
centromere The attachment point of two sister chromatids; also serves as point of attachment of spindle fibers during mitosis.
cephalization The presence of a "head" region, usually containing nerve tissue and supplied with sense organs.
cephalothorax A body region consisting of a fused head and thorax.
cerebellum A part of the brain; monitors and adjusts body activities involving muscle tone, body posture, and equilibrium.
cerebral cortex The gray matter of the cerebrum.
cerebrospinal fluid The fluid which nourishes and protects the brain and spinal cord and that flows between the two inner meninges.
cerebrum The part of the brain containing major motor and sensory centers; controls voluntary muscle activity; the area of conscious activity.
ceruminous glands Wax glands in the external auditory canal.
cervix The neck of the uterus where it narrows and joins the vagina.
chelicerae The first pair of appendages in arachnids; used for feeding; poisonous fangs in certain spiders.
chelipeds "Pinchers"; arthropods' appendages.
chemical change A change in which a substance loses its characteristics and changes into one or more new substances.
chemosynthesis A process whereby certain organisms obtain cellular energy from the breakdown of inorganic chemicals.
chemotherapy The use of chemical agents to treat a disease.
chemotropism Growth movement of a plant toward or away from certain chemicals.
chitin A chemical component in the exoskeletons of arthropods.
chlorophyll The green pigment of plant cells that is necessary for photosynthesis.
chloroplast An organelle that contains chlorophyll for photosynthesis.
cholesterol A common sterol found in the membranes of animal and human cells.
chorion In an amniotic egg, an embryonic membrane that becomes closely joined to the inner surface of the egg membrane; in humans, becomes part of the placenta.
choroid The thin middle layer of the eyeball; contains blood vessels for nourishing the retina.
chromatid, sister One of the two DNA duplicates that comprise one chromosome (when the chromosome is not separated).
chromatin material A complex of DNA and surrounding proteins in the nucleus of a cell.
chromatophores Skin cells that contain pigments.
chromosomes Strands of DNA complexed with proteins; usually found within the cell's nucleus.
chrysalis A protective sack found in the pupa stage of metamorphosis of some insects.
chyme The semiliquid mixture of partly digested food and digestive juices in the stomach and small intestine.
ciliary muscle A muscle that supports the lens of the eye and can change shape of the lens.
ciliate A protozoan that possesses cilia.
cilium (pl., cilia) One of numerous short extensions of the cell's plasma membrane; aids in movement.
circumcision The surgical removal of the foreskin.
classify To assign an organism to a particular classification group.
cleavage The division of a cell; the phase in development of an embryo during which the zygote divides.
climax vegetation The predictable plant community that would normally be found in an area if it were not disturbed.
clitellum The swollen region in the anterior of an earthworm; secretes the cocoon that contains the eggs.
cloaca The terminal portion of the digestive tract in certain vertebrates that serves as a common passageway for the elimination of urine and feces.
clone A group of organisms produced asexually; the process of reproducing organisms asexually.
coagulation The formation of a blood clot.
coccus (pl., cocci) A spherical bacterium.
cochlea A snail-shaped division of the inner ear that functions in sound perception.
codon A triplet of nucleotides that forms the code for a particular amino acid on messenger RNA.
coelom The body cavity.
coenzyme A nonprotein substance that helps to form the active portion of an enzyme.
cohesion The force that holds molecules together; characteristic that causes water to move up plant stems.
colchicine A poison that disrupts the spindle fibers during cell division, resulting in polyploid cells.
collar cells Flagellated cells that line the inner cavity of a sponge.
collenchyma A strengthening tissue in plants.
colloid A mixture of fine particles, often including protein molecules; these particles do not settle out.
colonial organism An organism that consists of a group of similar cells living together. Each cell functions like a unicellular organism.
columnar A type of growth in plants typified by a crown of leaves atop a nonbranching stem as in palm trees.
commensalism A relationship in which one population benefits from a second population, but the second population is not harmed nor helped by the first.
common ancestor A hypothetical organism that supposedly gave rise to two or more types of organisms.
communicable disease A disease that can be spread from one organism to another.

competition The relationship in which two populations inhibit each other because they both depend upon the same resource.
complex tissue A tissue that is made up of different types of cells.
compound A substance composed of two or more elements combined in definite proportions.
compound eyes Eyes composed of many individual lenses.
compound leaf A leaf having several blades on a single petiole.
concentration gradient The difference between the number of molecules in one area as opposed to the number of the same molecules in an area nearby.
conditioned behavior A behavioral response learned by experience.
conidiophore A fungus sporophore that forms asexual conidia by repeated divisions at its tip and not in an enclosure.
conjugation A temporary union of two organisms or cells for the one-way transfer of genetic material; type of sexual reproduction.
connective tissues Tissues of the body that connect, support, cushion, and fill spaces around organs.
conservation, law of The concept that the quantities of matter and energy in the universe are constant, not being created or destroyed.
constriction A method of suffocating prey by squeezing it.
consumer An organism that takes materials from the ecosystem.
contact infection A disease spread by direct contact with a sore, lesion, or mucous membrane of an infected person.
contamination infection A disease that enters the body by way of a contaminated food or water source.
contractile vacuole A vacuole, found in some cells, which collects water and expels it from the cell.
control group The group in an experiment that is not exposed to the experimental variable.
controlled experiment An experiment testing two identical groups for a single variable.
cork cambium A layer of cells under the epidermis that produces cork cells for protecting the stem of woody plants.
corm A short, upright, underground stem that produces aerial leaves at its top.
cornea The transparent anterior portion of the sclera of the eye.
corolla The collective name for the petals of a flower.
coronary thrombosis A thrombus (blood clot) in the coronary arteries that supply the heart muscle.
corpus luteum The structure formed in the follicle of the ovary after ovulation; forms several hormones.
cortex The region of thin-walled parenchyma cells that stores food just inside the epidermis of a root or stem.
cotyledon The leaf in a seed; the first leaf or leaves that emerge through the soil during germination.
countershading A form of camouflage coloring in certain animals; one color on the top side of the animal and another color on the bottom side of the animal.
covalent bond A chemical bond formed between atoms as a result of sharing a pair of electrons.
cranial nerves Nerves originating from the brain.
creationist One who believes the Bible account of creation.
cristae The folds of the inner membrane of the mitochondria; contain enzymes necessary for cellular respiration.
crop A portion of the digestive tract that temporarily stores food.
crossing over The exchange of segments between homologous chromosomes during meiosis.
cross-pollination The process of fertilizing a flower with the pollen from another flower.
cud In ruminants, partially digested food regurgitated from the rumen for additional chewing to aid in digestion.
cuspids The cone-shaped teeth used for tearing food.
cutaneous sensations Sensations of cold, heat, pain, pressure, and touch received from receptors located primarily in the skin.
cuticle The protective, waxy covering found on the outer surface of the epidermis of plants; a dead layer of skin; noncellular covering of certain parasitic invertebrates.
cyclic Recurring in a series; that which can be used and reused in a recurring series of events.
cyst A structure similar to a spore that is formed as part of the life cycle of some organisms or when conditions become unfavorable; protective shell formed by parasite larvas.
cytokinesis The division of the cytoplasm in a dividing cell.
cytokinin (kinin) A substance that affects plant cells in many ways including stimulation of the division of cells.
cytology The study of cells.
cytolysis The bursting or disintegration of a cell.
cytoplasm All the material inside the plasma membrane of a cell, excluding the nucleus.
cytoplasmic matrix The colloid portion of the cytoplasm.
cytoplasmic organelles Specialized structures in cells, such as mitochondria, that accomplish various cellular functions.
cytoplasmic streaming A flowing of the cytoplasm inside the boundaries of the cell for moving the cell's contents.
cytoskeleton The internal structure of cytoplasm; made of microfilaments and microtubules.

dark phase (dark reactions) The phase of photosynthesis that does not require light.
data The recorded information from an experiment or survey.
daughter cells The two cells that result from a mitotic division.
daughter chromosomes The separated sister chromatids in a dividing cell.
deciduous Plants that shed their leaves before a period of dormancy.
deciduous teeth A child's first set of teeth.
decomposer An organism that breaks down dead organic matter into forms that can be used by other organisms.
deductive reasoning The process of beginning with known facts and predicting a new fact.
deficiency disease A disease caused by improper nourishment such as a lack of vitamins or minerals.
degenerate code A code in which there is more than one way to indicate something.
degeneration, law of In all natural processes there is a net increase in disorder and a net loss of usable energy.
dehumanization Ignoring the essential quality of man as a living, eternal soul.
dehydration synthesis The process whereby two molecules combine and a water molecule is released.
deliquescent A growth pattern of shrubs and trees in which the main stem branches repeatedly to form many small branches.
deluge The Genesis Flood (Gen. 6-8).
deluge fossil formation theory The belief that most fossils were formed by the Genesis Flood.
dendrite Part of the neuron that receives nerve impulses and transmits them toward the cell body.
dentin Bonelike tissue that forms the root of the tooth and the portion of the inner crown.
deoxyribonucleic acid (DNA) The nucleic acid that is located primarily in the nucleus; carrier of genetic information.
depressants Drugs that slow down the central nervous system; they may cause drowsiness and sleep.
dermis The thick inner layer of the skin.
detritus Dead organic matter.
diaphragm The muscle that separates the thoracic and abdominal cavities in mammals and man; the device under the stage of a microscope that regulates the amount of light on the specimen.
diastole The phase of the cardiac cycle during which the myocardium is relaxed and the heart chamber fills with blood.
diatom One of the unicellular algae of phylum Chrysophyta that have silicon in their cell walls.
diatomaceous earth Soil composed mostly of diatom cell walls.
dicot A plant in the class Dicotyledonae.
diffusion The random movement of atoms, ions, or molecules from an area of higher concentration to an area of lower concentration.
diffusion pressure The pressure for diffusion that is produced by the concentration gradient.
digestion The process of breaking a large molecule down into its component parts.
dihybrid cross A genetic cross dealing with two characteristics at the same time.
diploid The condition of having homologous pairs of chromosomes.
disaccharide A sugar composed of two monosaccharides.

dispersed particle The dispersed solid in a colloid.
dispersion medium The liquid medium in a colloid.
diurnal Active during the day.
division plate A structure formed by plant cells during cytokinesis to divide the cytoplasm.
DNA (See **deoxyribonucleic acid.**)
dominant generation The stage that is most often seen in the life cycle of a plant.
dominant trait The characteristic that is expressed even in the presence of the recessive genes.
dormancy A period of greatly reduced activity in organisms.
dorsal On or near the upper surface (the backs of bilaterally symmetrical animals and humans).
Down's syndrome (mongoloidism) A genetic disorder caused by a trisomy of the twenty-first chromosome.
drone A haploid reproductive male in a bee colony.
droplet infection A disease transmitted through the air by pathogens suspended in water droplets.
drug A chemical that causes a change in the function or structure of a living tissue.
ductus arteriosus A short blood vessel in the unborn and newborn baby that connects the pulmonary artery with the aorta.
duodenum The first section of the small intestine.
dura mater A tough membrane covering the brain and spinal cord.
dynamic equilibrium An organism's maintaining a steady, balanced living state by expending energy; the ability of the body to respond automatically to position changes while it is moving.
dystopia A wicked, oppressive society resulting from man's corrupt use of knowledge.

ecological niche What an organism does and its relationship to and effect on its habitat.
ecology The whole science of the relationships between an organism and its environment.
ecosystem The total system of interactions between living organisms and nonliving things and factors within a limited area.
ecotype A subgroup of a species that survives best in a particular environment; often will not interbreed with other ecotypes.
ectoderm The outer germ layer in an embryo; the outer tissue layer in some animals.
ectoplasm The thin cytoplasm on the outer perimeter of a cell.
ectothermic Animals that are not able to maintain a constant body temperature; body temperature varies with the temperature of the environment.
effector A body part (such as a muscle or gland) that responds to a stimulus as a result of a nerve impulse transmitted along neurons.
egestion The elimination of nonsoluble, undigested wastes.
electrocardiogram (ECG or EKG) A tracing made by an apparatus that records the impulses produced by the conduction system of the heart.
electroencephalogram (EEG) A tracing made by an instrument used to measure brain waves.
electron That part of the atom that has a negative charge and that moves in a shell-like orbit around the nucleus.
element A substance that cannot be broken down into simpler substances by chemical reactions.
elongation region The area of a plant where cells extend in length.
embolus A thrombus lodged in a blood vessel.
embryo In animals, the young of an organism in early stages of development; the young before hatching; the time when organs and systems are developing; in plants, the plant within the seed.
embryology The study of the development of the embryo.
embryonic membranes The amnion, yolk sac, chorion, and allantois.
embryo sac The sac in a plant ovule that contains the haploid cells resulting from the division of the megaspore mother cell.
emulsification The process by which liquid fats are made into small droplets within another liquid.
endocardium The inner lining of the heart chambers.
endocrine system A system of glands which secrete hormones.
endoderm The inner germ layer in an embryo; forms lining of digestive and respiratory tracts, bladder, and urethra.
endodermis The single cell layer inside the cortex of a young root or stem; regulates the passage of substances into the vascular tissues.
endoplasm The dense cytoplasm found in the interior of a cell.
endoplasmic reticulum A cellular structure consisting of a complex network of fine, branching tubules.
endoskeleton An internal skeleton usually composed of bone and cartilage; characteristic of vertebrates.
endosperm The stored food that is used by the embryo in a mature seed.
endospores An asexual spore that forms within a bacterium.
endosteum The lining of the marrow cavity in a long bone; involved in bone growth and repair.
endothermic Maintaining a constant body temperature; an energy-consuming chemical reaction.
endotoxin A toxin produced by a cell; released only after the death and disintegration of the cell.
energy The ability to do work.
energy, kinetic The energy of motion.
energy, potential Stored energy.
entropy A measure of the unusable energy that escapes when energy is being converted from one form to another; an increase in disorder and degeneration.
environmental determinism The concept that the environment determines an individual's characteristics.
enzymes Protein molecules that are produced by living cells to catalyze specific reactions.
epicardium Connective tissue covering the muscular tissue of the heart.
epicotyl (plumule) The portion of the plant embryo above the point of attachment to the cotyledons that becomes the stem and leaves.
epidermis In plants, the outer layer of cells which usually lack chlorophyll and serve for protection; in animals and humans, a tissue that usually covers or lines a structure.
epididymis (pl., epididymides) A coiled tube that stores sperm.
epinephrine Adrenalin; a hormone secreted by the adrenal medulla that stimulates reactions needed in an emergency.
epiphyseal plate (growth plate) A thin, internal layer of cartilage tissue between the shaft and each epiphysis in a long bone.
epiphyses The ends of a long bone.
epiphyte A plant which grows on another plant but is not parasitic.
epithelial tissue A tissue of the body that covers or lines a body part; functions in absorption, secretion, and protection.
erythrocyte A red blood cell.
esophagus The tube connecting the pharynx and stomach.
estivation A period of inactivity and slowed metabolism whereby some animals escape unfavorably hot weather conditions.
estrogens Female sex hormones that stimulate the development of secondary sex characteristics.
etiolated The condition of a plant when grown in the absence of light; thin, elongated stems with small, pale leaves.
eucaryotic cells Cells that possess both organelles and a nucleus that is surrounded by a nuclear membrane.
eugenics The science that deals with improvement of the human race by applying principles of genetics.
euphoria Feeling of well-being caused by a slight disorganization of mental processes, often induced by drugs.
euploidy A chromosomal change that involves the addition or loss of entire genomes.
Eustachian tubes Tubes leading from the pharynx to the middle ear space to equalize air pressure.
euthanasia "Termination of human life by painless means for the purpose of ending severe physical suffering" (from the Euthanasia Society of America).
euthanasia, active Ending a person's life by either administering something that will kill him or removing a life-sustaining apparatus.
euthanasia, passive Ending a person's life by withholding treatment that could sustain life.
evolution, theory of A composite of ideas involving the philosophy of evolution, the theory of beginnings, and biological evolution.

evolution, theory of biological (organic evolution) The theory of the beginning of life and the slow process of organisms becoming more complex.
evolution, philosophy of The theory that all things are progressing toward a future perfection.
evolve To change; to become more complex.
excretion The elimination of soluble wastes.
excurrent A cone-shaped branching pattern in trees and shrubs.
excurrent pore The osculum, the opening of the sponge's body that expels water.
excurrent siphon The tube that expels water from the body of a mollusk.
exon A section of RNA that is kept when forming messenger RNA.
exoskeleton A system of external plates that protect and support.
exothermic Giving off energy by a chemical reaction.
exotoxin (soluble toxin) A toxin that diffuses from a microorganism into the surrounding tissue while the pathogen is still alive.
experimental group The group in an experiment that is exposed to the experimental variable.
experimental variable The factor being tested in an experiment.
expiration Breathing air out of the lungs.
expiratory reserve volume The amount of air that can be forced out of the lungs after a normal expiration.
external auditory canal The canal from the outer ear to the eardrum.
external digestion The process in which enzymes are secreted to digest food outside the organism.
external fertilization The uniting of the sperm and egg outside the organism.
external respiration The passage of oxygen from the air in the alveoli into the blood.
extracellular digestion The breakdown of substances that occurs in spaces outside the cells such as within the stomach or intestine.
eyespot A light-sensitive area of some organisms.

fallacy A false idea; that which is contradicted by scientific evidence or God's Word or both.
fang Needlelike teeth of a reptile used to inject poison into prey.
fat The most abundant type of lipids; composed of glycerol and fatty acid.
feces Waste material of an organism.
fermentation, cellular The anaerobic breakdown of carbohydrates to pyruvic acid, and then to alcohol and carbon dioxide or lactic acid.
fertilization The process of forming a zygote; the union of gametes.
fetoscope A fiber optic device which can be inserted into the womb to take pictures of the unborn child.
fetus The term applied to an embryo; in humans, the unborn child from the second month of development until birth.
fibrin An insoluble protein involved in blood clotting; forms a fine, interlacing network of filaments that traps blood cells.
fibrinogen A protein produced by the liver; involved in blood clotting.
fibrovascular bundle In herbaceous plants, a bundle composed of vascular tissues surrounded by fibrous tissue.
filament A chain of cells; the stalk of the stamen.
flagellate An organism with one or more flagella.
flagellum (pl., **flagella**) A long, tubular extension of a cell's plasma membrane that aids in movement.
flame cells Cells that possess tufts of cilia; part of the planarian's excretory system.
follicle A small saclike structure in the ovary that encloses an immature ovum; the tube from which a hair grows.
fontanel One of the fibrous membranes that fills the spaces between the skull bones at birth, forming the "soft spot."
food chain The nutritional relationships between organisms in an ecosystem.
food web A method of illustrating multiple nutritional relationships and interactions between populations in an ecosystem.
foramen ovale An opening between the right atrium and left atrium of a newborn baby's heart.
fornication Any act of sexual relations between people not married to each other.
fossil Any evidence or remains of an organism.
fovea A small depression in the central region of the retina; contains a concentration of cones.
fragmentation A form of reproduction caused by the breaking of a colonial organism by a physical disturbance.
frond A leaf of a fern or a palm; a thallus that resembles a leaf.
frontal lobe The region of the brain that controls reasoning, communication, and commands for voluntary body movements.
fruit A ripened plant ovary with or without seeds.
fungicide A chemical substance used to kill or inhibit the growth of fungi.

gallbladder The pear-shaped sac on the underside of the liver; concentrates and stores bile.
gamete A haploid cell which can unite with another gamete to form a zygote.
gametophyte The stage that produces gametes in the life cycle of a plant.
ganglion (pl., **ganglia**) A mass of nerve tissue.
gap theory An interpretation of the Genesis creation account which states there was a long period of time between Genesis 1:1 and 1:2.
gastric ceca Finger-shaped organs, attached to an insect's stomach, that secrete enzymes for digestion of foods.
gastrovascular cavity The internal cavity of cnidarians where digestion and food circulation occur.
gastroderm The inner cellular layer of the digestive tract of cnidarians.
gel The semisolid state of a colloid.
gemmules In a sponge, internal dormant cluster of cells encased in a tough spicule-reinforced covering.
gene A segment of DNA capable of producing a specific amino acid chain (polypeptide) resulting in a particular characteristic.
gene linkage Genes arranged in a definite order on a chromosome.
gene mutation A changing of the gene itself, which alters the sequence of nucleotide bases within a gene.
gene pool All the genes (possible alleles) in a population of a given organism.
genetic disorder (inherited disorder) Any undesirable phenotype caused by genetic defects in an individual.
genetic engineering The manipulation of chromosomes or genes by methods other than normal reproduction.
genetic load The number of mutations in a given organism.
genetics The study of heredity.
genetic screen A mechanism that prevents badly deformed or genetically defective individuals from living and/or reproducing.
genome A complete haploid set of chromosomes of an organism.
genotype The genetic makeup of an individual organism.
genus A group of organisms that has one or more common characteristics; includes one or more species.
genus-species name The scientific name for an organism.
geotropism Growth movement of a plant in response to gravity.
germination The beginning of growth by a seed, spore, bud, or other structure following a state of dormancy.
germ mutation A mutation that affects the gamete-producing cells.
gerontology The science of aging.
gestation The period of pregnancy.
gibberellin A plant hormone that causes rapid elongation of stems.
gill A respiratory structure in aquatic organisms through which oxygen and carbon dioxide are exchanged; the thin, spore-producing membrane of certain fungi.
girdling Removing a ring of bark from a woody stem.
gizzard A thick-walled digestive organ that grinds food.
glial cell A type of cell dispersed throughout the nervous system which performs beneficial functions for neurons.
globulins Proteins found in the blood plasma.
glomerulus Blood capillaries found in the Bowman's capsule of the nephron.
glottis The space between the vocal folds.
glucagon A hormone that raises the blood sugar level; also stimulates breakdown of fats to form glucose.
glucose A common six-carbon simple sugar.

glycogen A polysaccharide; animal starch; branching chains of glucose molecules.
glycolysis The breakdown of glucose to pyruvic acid.
goiter A swelling of the thyroid gland.
Golgi body A membrane-bound organelle that deals with synthesis and packaging of materials.
gonad A reproductive organ.
grafting The joining of two plant parts, usually stems, so that their tissues grow together.
granum (pl., **grana**) Structures within chloroplasts that contain the chlorophyll and other pigments involved in photosynthesis.
gray matter Brain tissue composed mainly of neuron cell bodies and dendrites.
green glands Organs that excrete wastes in some malacostracans.
guanine A pyrimidine base in a nucleic acid molecule.
guard cell One of the cells surrounding a stoma that controls the opening and closing of the stoma.
gullet A food passageway into the digestive tract of an animal.
guttation The process whereby drops of water are forced through pores at the tip and edges of a leaf.

habitat Where an organism lives; the "address" of an organism.
half-life The length of time necessary for a radioactive substance to decay to half its original amount.
hallucinogen A drug that amplifies the senses, affects a person's judgment, and can produce hallucinations (visions).
halophyte A plant that grows in soil that has high salt concentrations.
haploid The condition of having only one member of each homologous pair of chromosomes; characteristic of gametes.
haustoria Hyphae of parasitic fungi which enter the host's cells to obtain nourishment.
Haversian system A unit of bone in compact bone tissue.
hemoglobin The red pigment of erythrocytes that transports oxygen and carbon dioxide.
hemophilia Bleeder's disease; a genetic disorder in which a blood chemical for blood clotting is not produced.
hemotoxin A type of venom that affects blood cells.
hepatic portal vein The vein that carries food-rich blood from the digestive organs to the liver.
herbivore (adj., **herbivorous animal**) An animal that eats plants.
hermaphrodite An organism that has both male and female reproductive organs.
heterocyst A large colorless cell in the filaments of certain cyanobacteria.
heterogametes Gametes which differ in size and shape.
heterosis (hybrid vigor) An increased capacity for growth or strength in a hybrid.
heterotroph An organism that depends upon other organisms for food.
heterozygous Having two different alleles at the same position (locus) on homologous chromosomes.
hibernation A state of extremely slow metabolism by which certain animals survive unfavorable conditions.
hilum The point where a seed (ovule) is attached to the ovary wall.
histology The study of tissues.
HIV (See **Human Immunodeficiency Virus.**)
holdfast The special structure that anchors an organism.
homeostasis The equilibrium or internal "steady state" that every living organism must maintain.
homologous pair of chromosomes Two chromosomes that have the same kinds of genes (alleles) in the same order.
homologous structures Organs that are similar in structure between two organisms; once thought to show evolutionary relationships.
homologue One member of a homologous pair of chromosomes.
homosexuality Sexual desire for members of the same sex.
homozygous Condition in which both alleles in one organism are the same.
hormone A chemical regulator; in plants, produced in meristematic tissues, effecting cell maturation; in animals, produced in ductless glands, carried in blood, affecting metabolism.
horny layer (stratum corneum) The dead outer cell layers of the epidermis, sloughed off by the body.
host An organism in or on which a parasite lives.
Human Immunodeficiency Virus (HIV) The AIDS virus.
humoral immunity An immunity to disease involving antibodies.
humus Dark material in the soil; composed of dead organic matter.
hybridization The crossbreeding of two genetically unrelated individuals.
hydrogen and electron transport system A series of aerobic reactions that gives off energy and combines hydrogen and oxygen to form water.
hydrolysis A reaction whereby a substance is split apart by the addition of a molecule of water.
hydrophilic Attracted to or having an affinity for water.
hydrophobic Not having an affinity for water.
hydroponics Growing plants in mineral solutions.
hyperopia An eye condition in which it is easy to focus on distant objects but not on near objects.
hypersecretion Excessive production of a substance.
hypertonic solution A solution in which the concentration of solutes is greater than in the cytoplasm of living cells.
hypha (pl., **hyphae**) The slender filaments that compose the mycelium of a fungus.
hypnosis State of being in a subconscious trance and submissive to the will of a hypnotist.
hypocotyl The stem portion of an embryonic plant in a seed.
hypoglycemia Low blood sugar; often caused by an overproduction of insulin.
hyposecretion Insufficient production of a substance.
hypothalamus That region of the brain that controls involuntary activities, emotional expressions, appetite for food, and release of certain hormones.
hypothesis An educated guess about the solution to a problem; when supported by sufficient facts, it may become a theory.
hypotonic solution A solution in which the concentration of solutes is less than in the cytoplasm of living cells.

identify To determine the group in which an organism belongs.
immune carrier An individual who transmits pathogenic organisms but does not show symptoms of the disease.
immunity (adj., **immune**) The ability to resist infection or to overcome the effects of infection.
implantation The process whereby the tiny embryo attaches to the uterine wall and forms the placenta.
inborn behavior A pattern of reaction and response that the organism has inherited and does not need to learn.
inbreeding The mating of closely related organisms.
incisors Flat, thin teeth used in gnawing, biting, and cutting food.
incomplete dominance The type of inheritance in which the alleles for expressing characteristics are neither dominant nor recessive.
incomplete flower A flower that lacks petals or sepals or either the stamen or pistil.
incubation period The time between infection by a pathogen and the appearance of the first symptoms.
incurrent pores Tiny openings in the sponge's body for the intake of water.
incurrent siphon The tube that draws water into a mollusk.
independent assortment, concept of The Mendelian idea that the separation of one set of alleles during gamete formation is not affected by the separation of another set of alleles.
index fossil The remains of an organism that was believed to have lived only at a certain time in evolutionary history.
indicator organism An organism that is characteristic of a particular environment.
individual characteristics Characteristics that differ among members of a species; variations.
inductive reasoning A process of beginning with many facts or assumptions in order to reach a general conclusion.
infection The condition of the body after it has been invaded by harmful organisms.
infectious disease A disease caused by a pathogen.

inflammation The reaction of tissues to injury or infection; characterized by increased flow of blood, redness, pain, and swelling.
infusion A nutrient-rich solution in which microorganisms can live.
ingestion The intake of food.
inherited disorder (See **genetic disorder.**)
inhibitor gene A gene that prevents the expression of other genes.
initiator codon A codon that codes for amino acids that bond in only one direction; starts the polypeptide chain of amino acids.
innate behavior Inborn behavior; includes reflexes and instinct.
innoculate To expose to a substance.
inorganic Substances that lack carbon (with few exceptions); usually derived from non-living material.
insecticide A chemical or agent that destroys insects.
insectivorous plants Plants that capture and digest insects.
inspiration Filling the lungs with air.
inspiratory reserve volume The amount of air that can be forced into the lungs beyond a normal inspiration.
instinct Elaborate, often highly complex inborn behaviors.
integuments The protective folds over a plant ovule.
intelligent behavior Behavior marked by analysis, thought, emotion, reasoning, use of tools, and use of symbols; motivated by reasoning or intelligence.
interferon A protein substance or substances produced by cells exposed to viruses; acts to slow the spread of a virus.
intermediate host An animal that temporarily harbors an immature form of a parasite.
internal cellular membranes The cellular membranes found inside the cell forming the boundaries of organelles and other cellular structures.
internal fertilization The fertilization of the ovum inside the female's body.
internal respiration The passage of gases between the blood and the body cells.
interneuron A neuron located in the central nervous system; transmits an impulse from a sensory neuron to another neuron.
interphase A period of time between cellular divisions.
intestinal flora Nonpathogenic microorganisms that live in the intestines and function to protect the body against pathogens.
intestine A section of the digestive system where most of the digestion and absorption of foods usually occurs.
intracellular digestion The breakdown of substances within cells.
intracellular parasites Organisms that live inside the cell.
intron A section of RNA that is cut out when forming messenger RNA.
invaginate To pinch in; the method of cytokinesis in animal cells.
invertebrate An animal that lacks a backbone or vertebral column.
ion An atom or group of atoms that has a positive or negative charge as a result of losing or gaining electrons.
ionic bond A chemical bond between ions of opposite charge.
iris The colored portion of the eye.
irritability The ability to respond to changes in the environment.
islets of Langerhans Endocrine glands that consist of small groups of cells in the pancreas that secrete the hormones glucagon and insulin.
isogametes Gametes that are similar in shape and size.
isometric contraction A muscular contraction in which there is no change in the length of the muscle.
isotonic contraction A muscular contraction in which a body part is actually moved.
isotonic solution A solution that has the same concentration of solutes as the cytoplasm of living cells.
isotope One of the forms of an atom produced by having different numbers of neutrons in the nucleus.

Jacobson's organs Sensory pits used by a reptile in the sense of smell.

karyotype An illustration in which the chromosomes of a cell are arranged according to their size.
keel The ridge on a bird's sternum.
kinetosome A basal body.

labial palp A sensory appendage on the labium of an insect.
labium Lower mouthpart of an insect.
labrum Upper mouthpart of an insect.
lacrimal gland The tear gland in the eye.
lactic acid fermentation The formation of lactic acid from glucose.
large intestine (colon) The part of the alimentary canal that extends from the small intestine to the anus.
larva An immature stage in the life cycle of many animals, usually different from the adult.
larynx The short passageway that leads from the pharynx to the trachea; the sound-producing organ; the voice box.
latent virus A virus that enters a cell and may remain inactive for long periods of time.
lateral buds Buds at the base of the petiole; buds on the sides of a branch.
lateral line A canal that runs the length of a fish's body that detects vibrations in the water.
layering A method of vegetative reproduction in which a branch is exposed to the soil, allowed to form roots, and then separated from the parent plant.
leaflets The blades of a compound leaf.
leaf scar A layer of cork cells left on the stem after a leaf falls.
leaf venation The pattern of the veins of a leaf.
leafy shoot A stem-and-leaf-like arrangement that lacks water conducting tissues.
learned behavior Conditioned behavior, learned by repetition and often motivated by reward or punishment.
lenticel Small openings in the cork layer of older woody roots and stems through which air is admitted into the plant.
lethal Causing death.
leucocyte A white blood cell.
leucoplast Colorless plastid used as a storehouse in a cell.
life A highly organized cellular condition which is derived from preexisting life; requires energy to carry on processes such as growth, movement, reproduction, and response, and faces death.
ligaments Bands of connective tissues that hold a joint together.
lignin A substance that makes a secondary cell wall rigid.
limiting factor Something that in some way restricts the growth or existence of an organism.
lipids Organic compounds that are insoluble in water but soluble in certain organic solvents.
liver The largest organ in the body; secretes bile, purifies blood, metabolizes food molecules, and stores minerals and vitamins.
loam A soil mixture of sand, silt, and clay.
locus (pl., **loci**) The specific location of a gene on a chromosome.
logical reasoning A process of arriving at a conclusion through a series of ordered steps.
long-day (day-age) theory An interpretation of Genesis that states that each day of the creation week was actually a long time period.
lunar rhythm A cycle of activities that synchronizes with the moon.
lung A structure for the exchange of gases between the atmosphere and the blood of an organism.
lymph The fluid found between body cells; absorbed in the lymphatic system and returned to the bloodstream.
lymph node A small mass of tissue through which lymph passes and in which lymphocytes are produced.
lymphocyte A type of cell that produces antibodies that destroy foreign matter in lymph and blood.
lysis The rupturing of a cell.
lysosome A membrane-bound organelle that contains various hydrolytic enzymes.
lytic cycle The sequence of events whereby a virus replicates within a cell and eventually destroys the cell.

macronucleus An organelle found in certain protozoans; contains multiple copies of the cell's genetic material.
malignant tumor A tumor characterized by rapid and chaotic growth; often spreads and may be fatal.
Malpighian tubules Numerous threadlike tubules in insects that extract wastes from the blood and empty them into the intestine.

mammary glands Organs of mammals and humans which produce milk to nourish the young.
mandible Chewing mouthpart of an insect; lower jaw in vertebrates.
mantle The sheath of tissue that covers the body of a mollusk; also secretes the shell.
mantle cavity The space between the mantle and the body of a mollusk.
mass selection The method for selecting breeding stock in which only the desirable organisms are selected.
mastication The chewing of food.
matrix Nonliving material in a tissue; secreted by the tissue's cells.
matter Anything that occupies space and has mass (weight).
maturation region The area of a young root or stem in which the primary tissues are developed; area of cell differentiation.
maxilla Mouthpart that assists in chewing.
maxilliped One of the "jaw feet" that holds the food in place in some arthropods.
medulla The inner region of an organ.
medulla oblongata A part of the brain; the relay center between spinal cord and brain; contains several reflex centers.
medusa The free-swimming, umbrella-shaped stage in the life cycle of cnidarians; reproduces sexually.
meiosis Cell division in which the chromosome number is reduced from the diploid to the haploid state.
melanin A dark brown or black pigment.
melanocytes Cells in the human epidermis that produce melanin.
meninges The protective coverings of the brain and spinal cord.
menstrual cycle The process by which the uterine lining is prepared to receive an embryo.
menstruation The time during which the uterine mucosa is shed.
meristematic region An area in a plant containing young, rapidly-dividing cells.
meristematic tissues Plant tissues that are able to reproduce and become other plant tissues.
mesenchyme A noncellular, jellylike matrix between cell layers of a sponge; contains the amebocytes.
mesenteries The transparent membranes that surround body organs and attach them to the body wall.
mesoderm The middle germ layer in an embryo; the middle tissue layer in some animals.
mesoglea The jellylike layer found between the ectoderm and the endoderm of the cnidarians.
mesosome An organelle that appears as invaginations of the cell membrane in procaryotic cells; has enzymes attached to it.
messenger RNA (mRNA) The RNA molecule that carries the code for a polypeptide chain from the DNA.
metabolism The sum of all reactions that occurs in a living organism.
metamorphosis A change in shape or form that an animal undergoes in its development from egg to adult.
microbe A microscopic organism.
microfilaments Flexible, rodlike assemblies of protein molecules found in cells.
micronucleus The small reproductive nucleus in some protozoans.
micropyle A small opening between the integuments where the pollen tube may enter the ovule.
microtome A device used to cut thin sections of a substance.
microtubules Hollow, spiral assemblies of protein molecules that comprise flagella, cilia, mitotic spindles, and other cellular structures.
middle lamella A layer between two adjacent cell walls; composed primarily of pectins.
midline (median) Dividing into right and left halves (only for animals with bilateral symmetry).
midrib A large, central vein going to the tip of a leaf.
milt The sperm of certain aquatic animals; released into the water.
mimicry An organism's appearing like another organism; form of protective coloration.
miracle A direct act of God which sets aside natural laws or processes.
missing link A hypothetical organism that would fit between existing organisms listed on a phylogenetic tree.
mitochondria Membrane-bound cellular organelles responsible for the respiration of foods to release usable energy.
mitosis The duplicating and separating of a cell's chromosomes.
mixture A material that contains two or more substances.
model An explanation or representation of how something works.
molecular formula A description of a molecule that indicates the number and kinds of atoms in the molecule.
molecule The smallest possible unit of a substance that consists of two or more atoms.
molt To shed an exoskeleton, scales, feathers, or fur.
monocot Any flowering plant whose embryo has only one cotyledon. (Class Monocotyledonae)
monohybrid cross A genetic cross that deals with only one set of characteristics.
monosaccharide A simple sugar.
monosomy A condition in which there is only one of a homologous chromosome pair.
mother cell Any cell that is ready to begin cell division.
motor neuron A neuron that receives impulses from the central nervous system and stimulates muscles or glands.
mRNA **(See messenger RNA.)**
mucous membrane The thin membrane lining of many internal structures of the body; produces mucus.
mucus A slimy substance on the surface of mucous membranes and on the exterior of many fish and aquatic animals.
mulch Decomposing organic matter; often added to the soil to enrich its mineral content or texture and to preserve soil moisture.
multicellular An organism, organ, or tissue that consists of many cells.
multiple alleles The possible arrangement of three or more genes (alleles) for a trait at a single locus.
multiple gene interaction When two or more genes produce a cumulative effect on the same trait.
muscle fiber A muscle cell.
mutagen A substance that induces mutation.
mutation A random change in a DNA molecule.
mutation-selection theory (See **Neo-Darwinism.**)
mutualism A form of symbiosis in which the organisms depend on each other for protection and nourishment.
mycelium (pl., **mycelia**) All of the hyphae in a fungus plant.
mycoplasma A type of bacteria that lacks a cell wall.
myelin sheath The white, fatty membrane that protects neurons.
myocardium The muscular tissue of the heart.
myopia An eye condition in which only light rays from close objects can be focused accurately on the retina.

naiad An aquatic insect nymph that possesses gills.
narcotics Addictive drugs that induce a sense of euphoria, sleepiness, and anxiety; derived from opium or manufactured synthetically.
nastic movement Movements of some plants due to the loss of turgor in cells, such as the opening and closing of petals.
natural system of classification A taxonomy based on characteristics such as genetic similarities and reproductive capabilities.
nematocyst A stinging cell, characteristic of cnidarians, that contains poisonous barbs, coiled threads, or a sticky substance.
Neo-Darwinism (mutation-selection theory) An evolutionary theory proposing that mutations produce variations and that natural selection determines which variations will survive in order to produce biological evolution.
nephridia Tubelike structures that filter wastes from blood.
nephron A microscopic tubular unit of a kidney.
nerve impulse An electrochemical pulse that moves along the membrane of a neuron.
nerve net A nervous system which lacks a brain and major ganglia.
nervous tissue Body tissue capable of responding to changes and conducting electrical impulses.
neural arch The part of the vertebra that encloses the spinal cord.
neuron The functional unit of the nervous system; the cell that receives and distributes nerve impulses.
neurotoxin Venom that affects the nervous system.
neutralism The state in which there is no direct relationship between populations in an environment.

nictitating membrane A thin, transparent membrane that protects the eye and keeps it moist.
nitrifying bacteria Soil bacteria that carry on nitrogen fixation.
nitrogen fixation The process of converting atmospheric nitrogen to nitrogen-containing compounds.
nocturnal Active at night.
node The place where a leaf, root, or flower attaches to the stem.
noncyclic Not recurring in a series; that which is not used again.
nondisjunction The failure of a pair of homologous chromosomes to separate during meiosis.
norepinephrine (noradrenalin) A hormone secreted by the adrenal medulla; functions with adrenalin during stressful situations.
notochord A tough, flexible rod of cartilage, usually located along the dorsal side of an animal; supports the animal's body.
nuclear area A nonmembrane-bound mass of DNA and proteins in a procaryotic cell.
nuclear envelope (membrane) The double membrane forming the surface of the nucleus in eucaryotic cells.
nucleic acids Organic compounds in living cells that are responsible for passing on hereditary information; DNA and RNA.
nucleolus A spherical body in the nucleus that has a high concentration of RNA and proteins.
nucleotide The basic component of a DNA or RNA molecule; each is made up of a sugar, a phosphate, and a base.
nucleus The positively charged central portion of an atom; the region of a eucaryotic cell that contains the chromosomes.
nymph One of the stages of incomplete (gradual) metamorphosis in an insect.

objective The part of a light microscope that is near the specimen and contains lenses; that which forms an image of an object.
occipital lobe The brain region responsible for vision and memory.
ocular The eyepiece of a microscope; contains lenses.
olfactory lobe A part of the brain that receives impulses from smell receptors in the nostrils.
omnivorous animal An animal that eats both plants and animals.
oogenesis The meiosis process that forms ova.
oogonium (pl., **oogonia**) The structure that produces the ovum.
operculum (pl., **opercula**) A plate that covers the gills of a fish.
opium The dried juice of the unripe capsule of the opium poppy; an addictive drug that gives the user a sense of euphoria.
optic disc (blind spot) The area where the nerve fibers leave the eye to form the optic nerve; contains no photoreceptors.
optic lobe A division of the brain that receives impulses from the eyes.
oral groove The funnel-shaped indentation in the body of the paramecium; lined with cilia to sweep food into the mouth pore.
organ Tissues grouped together to perform a specific function.
organic Naturally derived from living organisms.
organic evolution (See **evolution, theory of biological.**)
origin The point of attachment of a muscle's tendon to a more stationary bone.
osculum The excurrent pore, the opening of the sponge's body that expels water.
osmosis Diffusion of water molecules through a semipermeable membrane.
ossicles The bones in the middle ear.
ossification The process of converting cartilage tissue into bone.
osteocyte A living bone cell.
ova (See **ovum.**)
oval window A membrane-covered opening of the inner ear.
ovarian cycle The process by which the ovary prepares and releases an ovum.
ovary In plants, the part of the pistil containing the ovules that mature into the fruit containing the seeds; in animals and humans, the primary sexual reproductive organ in females; produces ova.
oviduct Fallopian tube; tube transporting the ovum from the ovary to the uterus.
oviparous A method of reproduction in which young develop within eggs that are laid and hatched outside the body of the parent.
ovipositor An insect organ used to deposit eggs.
ovoviviparous A method of reproduction in which young develop within the egg that hatches in the body of the parent.
ovulation The release of ova from the ovary.
ovule A structure in a plant ovary that contains the egg cell and will mature into a seed.
ovum (pl., ova) A gamete formed by a female; usually nonmotile and larger than a sperm.
oxygen debt The amount of oxygen that must be supplied to change lactic acid to glucose during physical exercise.
oxyhemoglobin A molecule that forms as oxygen combines with hemoglobin in the blood.
oxytocin A hormone released by the posterior pituitary; stimulates the smooth muscle of the uterus to contract during birth.

palate The structure serving as the floor of the nose and the roof of the mouth.
palisade mesophyll The primary photosynthetic tissue in plant leaves that has the cells lined up side by side.
palp A structure near an organism's mouth, usually used in obtaining food.
pancreas An organ that secretes enzymes into the duodenum to perform digestion; also secretes hormones.
papilla (pl., **papillae**) A small bump on the tongue surface in which a taste bud is located; a tiny bump on the skin of a bird from which a feather protrudes.
parasite An organism that obtains its nourishment by living in or on another organism.
parasympathetic nervous system The neurons that help the body return to normal processes after a stressful situation.
parenchyma The tissue in plants comprising the pith, cortex, spongy tissue of leaves, and major parts of fruits.
parietal lobe The brain region responsible for most sensations, such as pain, pressure, touch, and temperature.
parthenogenesis Reproduction in which organisms develop from unfertilized ova.
passive absorption The process of water entering root epidermal cells because of differences in water concentrations.
passive mediated transport Passive transport that requires the presence of a protein factor in the cellular membrane.
passive transport The movement of substances through a cellular membrane without the expenditure of cellular energy.
pathogen An organism that causes a disease.
pathologist One who studies diseased tissues.
pectin A jellylike substance that helps solidify a cell wall.
pectoral girdle The part of the appendicular skeleton designed to support and provide attachment for the arms.
pedicel The stalk that supports the flower.
pedigree A diagram to show the characteristics of several generations of organisms.
pedipalps The second pair of arachnid appendages; used for sensory perception and sperm transfer.
pellicle A firm yet flexible covering outside the cell membrane of certain protozoans.
pelvic girdle The hip bones; designed to support and provide attachment for the legs.
penis The organ that transfers sperm from male to female.
perennial plant A plant that lives for many years.
pericardium A fibrous, slippery sac covering the heart and protecting it from rubbing against the lungs and chest wall.
pericycle A layer of meristematic tissue in a root.
periosteum A layer of fibrous tissue covering the shaft of a long bone; serves for muscle attachment and bone growth and repair.
peripheral nervous system The division of the nervous system containing the nerves that originate in the central nervous system and the sense organs.
peristalsis Muscular movements that move food in the alimentary canal.
petiole The stalk connecting the blade of a leaf to the stem.
PGA (See **phosphoglyceric acid.**)
PGAL (See **phosphoglyceraldehyde.**)

pH A symbol that is used with numbered values from 1 to 14 to indicate the concentration of hydrogen ions in a solution.
phagocytic vacuole A vacuole made by phagocytosis (cellular eating); a type of food vacuole.
phagocytosis The process of a cell engulfing a substance.
pharyngeal pouches Folds of skin along the neck region of vertebrate embryos that develop into either structures of the lower face, neck, and upper chest, or into gill openings.
pharynx The portion of the digestive tract that connects the mouth cavity and the esophagus; also serves as passageway for air from nose to larynx.
phenotype The physical expression of an organism's gene.
phloem A vascular tissue that usually carries water and dissolved foods downward in plants.
phosphoglyceraldehyde (PGAL) A three-carbon sugar produced during the dark phase of photosynthesis; also found in glycolysis.
phosphoglyceric acid (PGA) A three-carbon acid that forms from RuDP during photosynthesis; also forms during glycolysis.
phospholipid A molecule consisting of two fatty acid molecules and a phosphate group attached to a glycerol molecule.
phosphorescent Light-producing.
photolysis The breaking apart of a water molecule by energized chlorophyll.
photoperiodism The responses of a plant to changes in light intensity and length of days.
photo phase (light reactions) The phase of photosynthesis that requires light; consists of photolysis, hydrogen fixation, and the manufacture of ATP.
photosynthesis The process whereby simple sugars are formed from carbon dioxide and water in the presence of light and chlorophyll.
phototropism Growth movement of a plant in response to light.
phylogenetic tree A diagram that demonstrates the supposed stages of evolution.
physical change Altering a substance in its state of matter and appearance, without changing it into a new substance.
physical environment All the nonliving factors in an ecosystem.
physical withdrawal Actual physical symptoms that occur when a person stops taking a physically addictive drug.
physiology The science that deals with the various processes and activities that occur within a living organism.
phytoplankton Plankton that are photosynthetic organisms.
pineal gland A small structure in the brain which secretes melatonin.
pinocytosis The process whereby a cell takes in fluid by forming vesicles.
pistil The female reproductive structure that produces seeds in a flower.
pith The central area of a woody stem.
pith rays Plant tissues in young woody stems that extend laterally from the central pith to the xylem and phloem.
pituitary gland (hypophysis) An endocrine gland attached to the lower part of the brain.
placenta In plants, the structure that holds the ovule to the ovary wall; in animals and humans, the structure that consists of a portion of the uterine wall and chorion of the embryo: allows nutrient and waste exchange between mother and embryo.
plankton A tiny floating aquatic organism.
planula The free-swimming larval stage of some cnidarians.
plasma membrane The cell membrane; the cellular membrane that forms the outermost boundary of a cell's cytoplasm.
plasmodium A multinucleate mass of protoplasm that forms the vegetative body of a slime mold.
plasmolysis The shrinking of a cell's protoplasm when the cell loses water.
plastids Membrane-bound organelles found in plants, algae, and a few other organisms, but not in animals. (See also **leucoplast** and **chloroplast.**)
plastron The ventral part of the tortoise's bony shell.
platelet A small, colorless body found in the blood; lacks hemoglobin and a nucleus; involved in blood clot formation.
pleura A delicate membrane that lines the thoracic cavity and covers the lungs.
polar body A cell produced by meiotic division in oogenesis.
pollen A haploid cell that contains the tube and sperm nuclei of plants; produced in the anther.
pollen cone A structure on a conifer that produces pollen.
pollution Contamination of the environment with substances or factors that change the environment significantly.
polyp A sessile, tubular cnidarian with a mouth and tentacles at one end and a basal disc at the other; reproduces asexually.
polypeptide chain A chain formed by many peptide bonds, as in the formation of a protein by many amino acids being bonded by peptide bonds.
polyploid Any cell or organism that has multiple genomes.
polysaccharide A large, complex carbohydrate composed of many monosaccharides.
pons A rounded portion of the lower brain that relays information from one side of the brain to the other; contains reflex centers.
population All the members of the same type of living things within an area.
population genetics The study of the types and frequencies of genes in a given population.
portal circulation The flow of blood from the digestive organs to the liver.
postdiluvian After the Flood.
precocial chicks Birds that have a long incubation period and are usually able to care for themselves when they hatch.
predator An organism that eats another organism.
preening An activity in which a bird uses its bill to apply oil to its feathers and also to arrange them.
preformationist One who believes that completely formed organisms exist within sperm.
premolar The teeth in front of the molars used for crushing and grinding food.
primary growth The increase in length of a root or stem.
primary root The original root that sprouts from a seed.
primary tissue A plant tissue formed by the apical meristem; the plant tissues that result from primary growth.
procaryotic cell A cell that lacks a nuclear membrane and has only indistinct organelles; found only in kingdom Monera.
producer An organism that produces its own food; photosynthetic and chemosynthetic organisms are producers.
productivity The rate of photosynthesis carried on in an ecosystem.
proglottid A segment of a tapeworm's body.
prop root An adventitious root that helps to support the plant.
prostate gland A structure that produces a portion of the semen.
protein An organic compound that is composed of amino acids.
protein coat The structure which covers the nucleic acid core of a virus.
prothallus The heart-shaped gametophyte generation in ferns.
protonema A branched filamentous structure.
protoplasm All the living substances within a cell.
protozoan The general term given to microscopic organisms within the phyla Sporozoa, Ciliophora, Sarcodina, or Mastigophora.
pseudopod (pl., **pseudopodia**) A cytoplasmic extension of a cell; used for locomotion or engulfing substances.
psychotropic drug A drug that alters the emotional state of the user and often affects his sense of reality.
puberty The period of hormonal-induced change during which the secondary sex characteristics develop.
pulmonary circulation The flow of blood from the right ventricle to the lungs and back to the left atrium.
pulp cavity The central region of a tooth; filled with blood vessels, lymph vessels, nerves, and connective tissues.
punctuated equilibrium The theory that evolution occurs rapidly for a period of time followed by a long period of nonevolving before another period of rapid evolution.
Punnett square A diagram used to visualize genetic crosses.
pupa One of the stages of incomplete metamorphosis of an insect.
pupil The circular opening in the iris of the eye.
pure science Knowledge obtained through scientific activities.
pure strain An organism that is homozygous for certain traits.
pus A thick yellowish fluid composed of leucocytes, bacteria, and broken cells; characteristic of infections.

pyloric valve A muscular valve at the end of the stomach.
pyrenoid A protein-containing structure present in the chloroplasts of algae; center for starch storage.
pyruvic acid The organic acid formed during glycolysis.

quadrate bone A snake bone loosely attached to the skull and the jaw that enables the snake to open its mouth widely.
quarantine Strict isolation to prevent the spread of disease or pests.
quill The shaft portion of a feather that extends below the vane; the part of the feather in the skin.

rachis (shaft) The slender, central part of a bird's feather from which the barbs protrude.
radicle The portion of a plant embryo that will become the root.
radiocarbon dating method (carbon-14 dating method) A method of determining the age of fossils using the half-life of carbon-14 as a basis.
radiometric dating method A method of determining the age of an object by measuring the amount of a radioactive substance that is part of the object.
radula A platelike structure in the pharynx of certain mollusks; composed of rows of tiny teeth.
ray A cartilaginous or bony support in the fins of fish; the arm of a starfish.
receptacle The enlarged end of the pedicle; bears the flower parts.
recessive trait The characteristic that is only expressed in the homozygous recessive condition.
recombinant DNA DNA which has had a section of DNA that contains gene(s) spliced into it.
rectilinear movement Movement used by snakes; movement in a straight line with the aid of abdominal scutes.
rectum The muscular portion of the large intestine that contracts in order to rid the body of feces.
referred pain Pain that seems to be in one area of the body but actually originates in a different area.
reflection The image caused by light rays bouncing off an object.
reflex An automatic, involuntary response to a stimulus.
reflex arc A series of neurons which produces a single reaction in response to a stimulus.
refraction The bending of a light ray when it passes from one medium to another at an oblique angle.
renal circulation The flow of blood in and out of the kidneys.
replication The process whereby a DNA molecule duplicates itself and forms a new DNA molecule.
reproduction The formation of another organism that has characteristics and limitations similar to the original.
research An investigation into a topic often carried on by reading, inquiry, or scientific observation.
research method Using the scientific method to obtain knowledge.
residual volume The amount of air in the lungs after all of the vital capacity has been expired.
resolution The characteristic that allows a microscope to form a clear image of detailed structures.
respiration The release of energy from a food source.
retina The innermost layer of the eyeball; composed of specialized neurons and their fibers.
revealed truth The information that God has recorded in His Word.
rhizoid A rootlike structure that lacks water-conducting tissue.
rhizome A thick, fleshy, horizontal underground stem which produces leaves or leaf-bearing branches.
ribonucleic acid The type of nucleic acid that forms from DNA and functions with ribosomes to form protein molecules. (See also **messenger RNA, ribosomal RNA, and transfer RNA.**)
ribosomal RNA (rRNA) The RNA molecule that combines with proteins to form a ribosome.
ribosome A nonmembrane-bound cellular organelle associated with protein formation.
ribulose diphosphate (RuDP) A five-carbon sugar diphosphate that serves as a carbon dioxide acceptor in photosynthesis and then splits to form two molecules of PGA.
rickettsias A group of obligate parasites in the kingdom Monera.
ring canal A circular canal within the water-vascular system of an echinoderm.
RNA (See **ribonucleic acid.**)
root cap Thick-walled cells which cover and protect the delicate root tip.
root hair An outgrowth of epidermal cells of the root.
root pressure The pressure that causes water to move up the stem of a plant; caused by active absorption.
round window A membrane-covered opening of the cochlea.
rRNA (See **ribosomal RNA.**)
RuDP (See **ribulose diphosphate.**)
rumen The first of four chambers of the stomach of a ruminant.

salivary gland A gland in or near the mouth; secretes saliva to break down starches.
sanctity of human life The Biblical principle that human life has high value.
saprophyte A plant that obtains its nourishment from dead organic matter.
scale An epidermal plate on reptiles and fish; the small overlapping leaves of some gymnosperms.
science A body of facts that man has repeatedly observed about the physical universe around him.
scientific method A logical method of problem solving that involves observing and reaching a conclusion.
scientism An exaggerated trust in science; the "worship" of science.
scion The unrooted portion that is grafted into the stock; may be a bud or twig.
sclera The outer layer of the eye; "the white of the eye."
scolex The anterior end of a tapeworm.
scrotum A skin pouch within which the testes are located.
scute One of the broad scales on a snake that aids in movement.
sebaceous gland A gland of the skin that produces oil.
secondary growth The increase in diameter of stem and roots.
secondary sex characteristic A body characteristic caused by the sex hormones.
secondary tissue Any tissue that is manufactured in a plant after primary growth.
sedimentary rock Layers of rock formed by sedimentation.
sedimentation The settling out of materials due to the action of water or wind.
seed A mature plant ovule that consists of embryo and stored food enclosed by a coat.
seed cone The structure on conifers which produces the seeds.
segregation concept The Mendelian concept that only one gene for each characteristic may be carried in a particular gamete.
selection Nonrandom mating; may occur naturally or artificially.
selectively permeable membrane (See **semipermeable membrane.**)
semen The fluid that contains sperm.
semicircular canal A structure in the inner ear that maintains dynamic equilibrium.
semilunar valve A membranous structure located at the exit of each ventricle; permits one-way flow of blood.
seminal receptacle The storage vessel in an organism that receives sperm from another organism.
seminal vesicle An organ that produces a fluid that activates sperm.
seminiferous tubule One of the tiny tubes that produces sperm within the testes.
semipermeable membrane A membrane that is permeable to certain molecules or ions but not to others.
sensory neuron A neuron that carries impulses toward the spinal cord or the brain.
sepal An outermost flower structure; usually encloses the other floral parts in the bud.
septum (pl., **septa**) A wall that separates individual cells in fungi; the muscular wall separating the chambers of the heart.
serpentine movement A movement used by snakes for swimming and crawling; winding in a series of "S" curves.

serum The clear fluid (obtained from blood) that contains antibodies; used to transfer immunity to another person or animal.
sessile In organisms, growing while attached to something else; nonmotile; in leaves, lacking a petiole.
seta (pl., **setae**) A stiff bristle on a segmented worm; used for locomotion and sensation.
sex chromosomes Special chromosomes (in humans X and Y) that determine whether an organism will be male or female.
sex-limited characteristic A trait expressed in only one sex even though the genes are present in the autosomes of both sexes.
sex-linked Determined by genes located on the sex chromosomes.
sex-linked traits An inherited characteristic for which there is a gene on the X chromosome but not on the Y chromosome.
sexually transmitted disease (STD) A contagious disease spread by sexual contact with an infected person.
sexual reproduction The union of haploid gametes that results in a diploid zygote which develops into a new individual.
sheath A thick capsule that surrounds a colony of bacteria.
shoot apex The rapid-growing region of a stem where cells begin to differentiate into leaves, branches, and flower parts.
short-day theory An interpretation of Genesis which states that each day of the creation week is a literal 24-hr. period.
sickle-cell anemia A genetic abnormality that causes the production of abnormal hemoglobin which is unable to carry oxygen and that causes sickle-shaped red blood cells.
sidewinding Movement used by snakes; shuffling sideways by continually looping forward.
simple eye An eye with only one lens.
sinoatrial node (SA node) A small mass of specialized cardiac muscle located in the right atrium; performs the job of starting each systole; the pacemaker of the heart.
sinus venosus A thin sac at the back of the heart; receives deoxygenated blood and empties it into an atrium of the heart.
siphon A tube in a mollusk used to draw in or expel water.
sister chromatid Each single strand in the pair of DNA duplicates that is part of a chromosome ready to go through cell division; becomes a daughter chromosome during mitosis.
skeletal muscle Muscle tissue that is attached to and moves the skeleton.
skin gills Fingerlike projections on the surface of echinoderms; used for respiration.
small intestine The digestive organ where most of the digestion and absorption of food occurs.
sol The liquid state of a colloid.
solute The dissolved substance in a solution.
solution The uniform dissolving of one substance into another substance.
solvent The substance (often a liquid) in which a solute is dissolved.
somatic mutation A mutation that affects only body cells (not gametes).
sonography (See **ultrasonic scanning.**)
soredium (pl., **soredia**) An asexual reproductive structure in lichens; consists of a group of algal cells enclosed in fungus hyphae.
sori (sing., **sorus**) Groups of sporangia attached to the underside of fern fronds.
spawn The laying of eggs by aquatic animals.
species A population of organisms that are structurally similar but do have a degree of variation; those organisms that interbreed and produce fertile offspring.
sperm A gamete formed by a male; often motile.
spermatogenesis The meiosis process of sperm formation.
spicules Sharp, pointed, supporting structures in sponges; composed of silicon or calcium compounds.
spinal cord The nervous tissue that conducts messages between the brain and the peripheral body parts.
spinal nerve A mixed nerve attached to the spinal cord.
spindle Fibers that form between centrioles during cell division.
spine In plants, a stiff, hard, pointed outgrowth on stems; in animals, bony supports in fins; projecting part of a bone.
spiracles Small pores in an insect's body that function in breathing.
spirillum (pl., **spirilla**) A spiral-shaped bacterium.
spirochete A group of spiral-shaped organisms in the kingdom Monera.
spleen A lymphatic organ which filters blood, stores red blood cells, and destroys old red blood cells.
spongy bone The type of bone that contains many small spaces; located in the ends of a long bone.
spongy mesophyll The photosynthetic tissue in leaves that is formed of irregular-shaped cells and many airspaces.
spontaneous generation The formation of organisms from nonliving materials.
spontaneous mutation A chromosomal and gene mutation that occurs naturally.
sporangiophore A fungus sporophore that produces its asexual spores within an enclosure.
sporangium (pl., **sporangia**) A structure in which spores are produced.
spore A cell with a hard protective covering that is capable of producing a new organism.
sporophore A spore-producing hypha of a fungus mycelium; spore-producing stage in the life cycle of a plant.
stamen The male reproductive structure of a flower.
starch A polysaccharide; often used for energy storage.
statocyst An organ of equilibrium in Malacostracans.
STD (See **sexually transmitted diseases.**)
sternal sinus The collecting chamber for blood in some open circulatory systems.
stigma The expanded tip of the pistil that receives the pollen.
stipe The stalk of a mushroom.
stipule A structure at the base of the petiole of a leaf; often leaflike.
stock The rooted plant onto which a scion is grafted.
stolon (runner) In fungi, an aerial, horizontal hypha that produces new fungi asexually; in plants, a slender, branched, underground stem that produces new shoots.
stoma (pl., **stomata**) An opening between the guard cells of a leaf that permits exchange of gases.
stratum germinativum The deepest layer of the epidermis; carries on cell division.
stroma The fluid in a chloroplast.
structural defenses The body's first line of defense in preventing pathogens from entering the body, such as skin, tears, and stomach acid.
structural formula An expanded drawing that shows the arrangement of atoms and bonds within the molecule.
style The elongated portion of the pistil that supports the stigma.
subcutaneous layer The layer of fat and connective tissues below the dermis of the skin.
submucous layer The second layer of the alimentary canal.
substrate The chemical or chemicals an enzyme will affect.
succession The predictable, gradual change of a biotic community over a period of time.
succulent leaf A thick leaf with a tough cuticle; capable of storing water.
sucrose A common disaccharide; table sugar; made of one glucose molecule and one fructose molecule.
surrogate mother A woman who nurtures and brings to birth from her womb a child for which she did not provide the ovum.
survival of the fittest Part of Darwin's evolutionary theory; only the organisms best suited to their environment will survive.
suspension The state of a substance when its particles are mixed but are undissolved.
suture An interlocking margin of skull bones.
symbiosis Two organisms of different species that live together in close association.
symmetry A likeness in size, shape, or structure of parts of an organism.
sympathetic nervous system A system of neurons that helps the body adjust to stressful situations.
synapse A space between an axon and a dendrite or between the end of an axon and the body structure it affects.
synovial fluid A lubricating fluid in joints.
synovial membrane The lining of a joint cavity which fills the cavity with a lubricating fluid.

synthesis The process of putting things together in order to make new things.
syrinx The song box of a bird.
system A group of body organs that works together to perform one or more vital functions.
systematics The science of classifying organisms.
systemic circulation The flow of blood from the left ventricle to all parts of the body, except the lungs, and back to the right atrium.
systole The phase of the cardiac cycle when the myocardium contracts and the heart chamber pumps blood.

talons Long curved claws found on birds of prey.
tannic acid The product of the chemical breakdown of plant cell contents that causes a brownish color; found in tea.
taproot system The plant root system in which the primary root continues to grow as the main root.
taste buds Groups of cells near the tongue surface that produce taste sensations.
taxes (sing., **taxis**) An organism's response to a single stimulus.
taxonomy The science of classifying organisms.
T cell Any of several types of cells involved in cell-mediated immunity.
technical method The use of prescribed techniques to gain knowledge about a specific case.
tectorial membrane The membranous flap over the organ of Corti.
tegument A protective body covering.
telson The last abdominal segment of some arthropods.
temperate phage A virus which enters and replicates within a cell but may never destroy the cell.
template RNA Messenger RNA.
temporal lobe The brain region responsible for hearing and smelling.
tendon The connective tissue that attaches muscles to bone.
terminator codons Codons that end a chain of amino acids.
testa Seed coat.
test cross The mating of an organism that possesses a dominant phenotype but unknown genotype with an organism that possesses a recessive phenotype to determine the genotype of the dominate individual.
testes The primary male reproductive organs, which produce sperm and male sex hormones.
testosterone The male sex hormone that promotes the development of secondary sex characteristics; one of the androgens.
test-tube fertilization Under scientifically controlled conditions, the uniting of a sperm and an ovum to form a zygote outside the female's body.
tetraploid Having four complete sets of chromosomes (genomes).
thalamus The brain region that receives general sensations and relays impulses to the parietal lobe.
thallus (pl., **thalli**) A leaflike or plantlike structure in algae, fungi, and plants; not differentiated into true leaves, roots, or stems.
theistic evolution The interpretation of the Bible according to evolutionary theories.
theory An idea supported by many observations.
theory of evolution (See **evolution.**)
theory of inheritance of acquired characteristics An evolutionary theory that states that a characteristic acquired by an organism can be passed on to its offspring.
theory of natural selection A process that supposedly results in the survival of the organisms that are best suited for their environment.
theory of need An evolutionary theory which states that an organism must have a need for a structure in order to evolve it.
theory of recapitulation An evolutionary theory which states that all organisms go through their evolutionary history as they develop from a zygote to a mature organism.
theory of use and disuse An evolutionary theory which states that if an organ is used, it will keep evolving; if not, it will degenerate.
thigmotropism Growth movement of a plant in response to contact.
thorax A body region between the head and the abdomen.
thrombin A substance involved in blood clotting.
thromboplastin A substance released by platelets; triggers the conversion of prothrombin to thrombin during blood clotting.
thrombus A blood clot formed in a blood vessel or the heart.
thylakoids Flattened sacs in a chloroplast that form grana.
thymus gland A mass of lymphatic tissue thought to produce hormones; this degenerates prior to puberty.
thyroxine The thyroid hormone that regulates the metabolic rate.
tidal volume The amount of air that enters the lung during a normal inspiration or leaves the lung during a normal expiration.
tissue Many similar cells grouped together to perform a similar function.
tissue rejection The condition of a transplanted tissue or organ in which it stimulates the body's immune system to react.
tonic contraction A continual partial contraction of a muscle; muscle tone.
tonsil One of the masses of lymph nodes in the pharynx region.
topography Land features.
torsion A twisted body arrangement unique to gastropods.
total lung capacity The vital capacity and the residual volume.
toxoid A weakened form of a toxin used to stimulate immunity.
trachea A tube that extends from the larynx to the bronchi.
transcription The process of forming messenger RNA from DNA.
transfer RNA (tRNA) The RNA molecule that carries (transfers) a specific amino acid to the ribosome during protein synthesis.
transformation The genetic change that is produced when DNA from one bacterium is taken up through the membrane of another bacterium.
translocation The movement of water and dissolved substances in a plant; the transfer of a chromosome segment to a nonhomologous chromosome.
transpiration The release of water through the leaves of a plant.
transpiration-cohesion theory Possible explanation for water translocation in a plant; as water is released from the leaves, additional water molecules must enter the roots.
trichocyst An organelle in a paramecium which discharges a threadlike filament in response to stimuli.
triplet A series of three bases in DNA that has the code for one specific amino acid molecule during protein synthesis.
triploid Consists of three complete sets of chromosomes (genomes).
trisomy An abnormal condition in which there are three chromosomes in a set instead of two.
tRNA (See **transfer RNA.**)
trochophore The ciliated, free-swimming, larval stage of mollusks.
tropic hormone A hormone that stimulates the growth and function of other endocrine glands.
tropism A growth response of plants to external stimuli such as light, gravity, and touch.
tube feet Small soft, tubular structures in echinoderms; used for locomotion and food capture; part of water-vascular system.
tuber A storage stem which produces roots and often has "eyes" (buds) to produce aerial stems.
tubule A tiny tube.
tumor An abnormal growth of cells.
turbidity Cloudiness of water.
turgor (adj., **turgid**) The presence of water inside a plant or protist cell in quantity sufficient to give the cell stiffness.
turgor pressure The added pressure within a plant cell that results from the movement of water into the central vacuole.
tympanic membrane A circular membranous structure that serves to transmit sound vibrations to an ear cavity; the eardrum.

ultrasonic scanning (sonography) The use of sound waves to produce a computer-generated picture of internal structures.
umbilical cord The flexible structure that contains blood vessels and that conducts the blood of the fetus to the placenta for exchange of food, wastes, oxygen, and carbon dioxide.
understory Plants that grow in the shade of trees.
unicellular Consisting of a single cell.
unit characteristics concept One of the Mendelian theories which states that each characteristic of an organism is determined by a single gene.
universal flood A flood that covers the entire earth; the Genesis Flood, Noah's Flood.

unrevealed truth Natural laws that God has established but has not revealed in His Word.
unsaturated fat A fatty acid molecule in which some of the carbon atoms are double bonded to each other.
unviable Not able to germinate.
uracil The base in RNA that is comparable to thyamine in DNA.
ureter One of the tubes that conducts urine into the bladder.
urethra A passageway for urine; also the passageway for sperm in the male.
urinary bladder An organ designed as a reservoir for urine.
urine A liquid excreted from the body; contains the metabolic wastes from the blood.
uropod The flipper-shaped tail appendage of arthropods.
uterus A reproductive organ for storing ova until they are fertilized or laid; the womb; in most mammals and in humans, the organ in which the embryo develops.
utopia An ideal society.

vaccination A method of exposing a person to a controlled amount of a disease-causing factor to develop an immunity.
vaccine A weakened form of a pathogen used to build immunity by stimulating the body to produce antibodies or activate T cells.
vacuole A membrane-bound sac in a cell.
vacuole, contractile A cellular structure used to collect water molecules and keep cells from bursting.
vagina The elastic canal that leads from the outside of the body to the cervix of the uterus.
valid Anything that is meaningful, accurate, and reliable.
valve A mollusk shell.
vane The flat part of a feather; composed of parallel rows of barbs.
variable The factor in an experiment that is subject to change and is therefore the one being tested.
variations The differences between different individual organisms of the same kind; difference based on genotype; the expression of different individual characteristics in organisms of the same kind.
varieties Different forms or types of organisms within a species.
vascular cambium A layer of meristematic tissue between the xylem and phloem; produces secondary xylem and phloem.
vascular cylinder The central area of the young root or stem; contains xylem and phloem.
vascular tissue Tissues (xylem and phloem) that conduct water and dissolved materials in a plant.
vas deferens (seminal duct) The tube which carries the sperm from the testes to the urethra.
vector An insect or other arthropod that carries pathogens to other host organisms.
vegetative organ A leaf, root, or stem of a plant.
vegetative reproduction Asexual reproduction in plants.
vein Any blood vessel that carries blood toward the heart; fibrovascular structure for strengthening and conduction in plants.
venation The pattern of veins in a leaf.
ventral On or near the lower surface (or at the front of some organisms).
ventricle The chamber of the heart that pushes blood into the arteries; space within the brain.
vermiform appendix The narrow end of the cecum.
vertebrae (sing., **vertebra**) The bones or cartilaginous segments of the vertebral column.
vertebral column Bony or cartilaginous structures that are used in supporting an organism; the backbone.
vertebrate An animal that possesses a backbone or vertebral column; members of subphylum Vertebrata.
vesicle A small vacuole.
vestigial structure An organ which supposedly no longer has any function.
viable Capable of growing and developing.
villi (sing., **villus**) Microscopic fingerlike structures that line the small intestine.
viper A poisonous, long-fanged snake of the Old World.
virulence The ability of a virus or other pathogen to cause a disease.
virus A submicroscopic, noncellular particle, composed of a nucleic acid core and a protein coat; obligate parasite.
visceral Relating to internal organs.
visceral hump The portion of a mollusk's body that contains internal organs.
visceral muscle Muscle tissue that forms the walls of internal organs.
vital capacity The sum of the tidal volume, inspiratory reserve volume, and expiratory reserve volume.
vitalism The theory that the activities of living organisms are controlled by a vital force.
vitamin An organic substance other than proteins, fats, and carbohydrates that is necessary for normal metabolism, growth, and development.
vitreous humor A clear, jellylike substance in the eyeball.
viviparous A method of reproduction in which the young are born alive after being nourished in the uterus through a placenta.
vocal sacs A pair of sacs in the mouth region of male frogs.
vomerine teeth A set of inconspicuous teeth that protrude from the roof of the mouth of some animals.

water-vascular system A series of canals and tubules that are used for locomotion and food capture in echinoderms.
womb A place where the unborn baby is protected and nourished; the uterus.
workability A characteristic of scientific knowledge that allows its practical application.
wound infection A disease caused by pathogens entering the body through wounds.

xylem A vascular tissue that carries water and dissolved minerals upward in a plant.

yolk Food material stored in an egg to nourish the embryo.
yolk sac The membrane that contains the yolk in an amniotic egg.

zoology The study of animals.
zooplankton Plankton which are tiny animals or protozoans.
zoospores A motile, swimming spore; possesses cilia or flagella.
zygospore A zygote surrounded by a hard, protective covering to survive unfavorable conditions.
zygote A diploid cell formed by the union of two haploid gametes.

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